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Simultaneous Activation of Reading Mechanisms: Evidence from a Case of Deep Dyslexia

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We report the performance of LC, a deep dyslexic. We investigated extensively her errors according to serial cognitive neuropsychological models of oral reading. Initial evaluation of her reading suggested impaired access to the phonological output lexicon (POL). Impaired grapheme-to-phoneme conversion (GPC) and semantic errors in reading suggested that LC read via an impoverished semantic route. However, a serial model of oral reading could not explain error differences in reading, picture naming, spontaneous speech, and repetition. Neologisms occurred in oral reading but not in spontaneous speech and repetition. Semantic errors in naming exceeded those in oral reading. To account for these different error patterns we propose that the semantic route, the direct route from the orthographic input lexicon to the POL, and GPC activate simultaneously during reading, converging at the POL to constrain phonological selection. These routes are modular but not functionally encapsulated. For LC, the POL receives ambiguous information due to degradation of all routes, causing reading errors.

INTRODUCTION

The notion that language is composed of functionally encapsulated modules is not new (Fodor, 1983). Double dissociations in behavior (for example, the inability to read nonwords and competent reading of irregular words) observed after brain damage offer insights into the mental organization of words and their meanings (lexical semantics). These dissociations are crucial in establishing the existence of distinct modules. Early descriptions by Mar-

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shall and Newcombe (1966, 1973) of preserved and deficient abilities in different dyslexias (deep, surface, and phonological) add support for the notion of the modularity of language.

Based on the descriptions of preserved and deficient abilities in acquired dyslexics (Marshall & Newcombe, 1973; Patterson, 1978; Beauvois & Derouesne, 1979; Coltheart, 1980) cognitive neuropsychological models incorporate three mechanisms for word reading. For skilled readers the normal mechanism for reading words aloud is via the semantic system. The orthographic input lexicon (OIL) activates semantic representations, which in turn activate phonological entries in the phonological output lexicon (POL) (Ellis, 1984; Ellis & Young, 1988). Evidence for reading via semantics comes from observations of phonological dyslexics. These patients cannot read nonwords but can read and comprehend real words (Beauvois & Derouesne, 1979; Shallice & Warrington, 1980; Patterson, 1982; Funnell, 1983).

No reader has representations for all words in the OIL. There must be another route from print to pronunciation, allowing pronunciation of unfamiliar words and nonwords (see Shallice & Warrington, 1980, for the possibility that several distinct sublexical correspondences may exist). Grapheme-to-phoneme conversion (GPC) is the mechanism that translates letter strings into phoneme strings, assembling a phonological entry for a word (Patterson, 1978; Coltheart, 1985; Hillis & Caramazza, 1991; Ellis & Young, 1988). This functional and conceptual separation between lexical and GPC information comes from observations of the inability of phonological and deep dyslexics to read nonwords (Coltheart, 1985; Newcombe & Marshall, 1980a, 1980b). Surface dyslexics, on the other hand, can read regular words but not irregular words (Marshall & Newcombe, 1973; Bub, Cancelliere, & Kertesz, 1985; Beauvois & Derouesne, 1979). These observed dissociations in acquired dyslexics corroborate the notion of a functionally independent GPC subsystem.

Some brain damaged patients can read words, including irregular words they do not comprehend (Ellis & Young, 1988; Bub et al., 1985; Funnell, 1983; Schwartz, Saffran, & Marin, 1980; Sartori, Masterson, & Job, 1987). Others are capable of reading words but are impaired at naming pictures (Breen & Warrington, 1994, 1995; Hillis & Caramazza, 1991). These dissociations argue conceptually for a direct nonsemantic route by which information from the OIL addresses directly a phonological entry in the POL.

All these reported dissociations in acquired dyslexics provide testimony that language consists of relatively independent subsystems or modules responsible for specific linguistic tasks (Coltheart, 1987). Selective impairment of these modules after brain damage supports the notion that language involves modular, functionally encapsulated systems (Fodor, 1983). In the traditional sense, functionally encapsulated modules transform inputs to outputs without assistance from other operations (Fodor, 1983). In other words, these modules are independent and do not interact. Serial models of oral reading incorporate the notions of non-interaction and functional encapsulation of modules during reading. A basic assumption of serial models is that word reading occurs either via the semantic system or via GPC but not both (Massaro & Cohen, 1994). The semantic route and the nonlexical GPC mechanism race to produce a pronunciation. The pronunciation of a written word is generated by the mechanism that reaches the POL first (Massaro & Cohen, 1994; Henderson, 1982; Norris & Brown, 1985; Patterson & Morton, 1985). No interaction occurs between information from these two mechanisms. Generally, the semantic mechanism dictates the activation of a phonological entry with minimal input from the nonsemantic mechanisms. Nonsemantic input only influences activation of a phonological entry when semantic processing is slow (Patterson & Coltheart, 1987; Hillis & Caramazza, 1991; Miceli, Capasso, & Caramazza, 1994).

Reading performance in deep dyslexia is explained by the selective impairment of one or more functionally encapsulated modules. Impaired GPC accounts for the inability to read nonwords (Coltheart, 1980). Impaired access to the POL or an additional deficit within or around the semantic system may be responsible for other errors (Ellis & Young, 1988; Coltheart, 1987; Nolan & Caramazza, 1982). Impairment to a particular module (e.g., the semantic system) predicts that performance on any lexical task requiring this component should be similar (Hillis & Caramazza, 1991). For example, if impaired access to the POL accounts for phonological reading errors quantitatively and qualitatively similar errors should occur in spontaneous speech, picture naming, and repetition (Nolan & Caramazza, 1982; Caramazza, Berndt & Basili, 1983; Friedman & Kohn, 1990). Unfortunately, few studies have evaluated performance of deep dyslexics across other lexical tasks. Limited information on deep dyslexics performances across other lexical tasks makes it difficult to determine if serial models best account for their reading performance.

Deep dyslexics may not perform in a similar manner across different lexical tasks requiring the same independent processing mechanism (Hillis & Caramazza, 1991; Miceli et al., 1994; Breen & Warrington, 1994, 1995). Specifically, marked dissociations occur between oral reading and naming. In some patients oral reading is intact but naming is poor (Breen & Warrington, 1995; De Renzi & di Pellegrino, 1995). Goldblum (1985) reported the opposite dissociation. Oral reading was impaired but comprehension and naming were relatively well preserved. Current models of reading assume that reading and naming have several serial levels of processing in common: visual analysis, semantic access, accessing the POL from semantics, and selection and sequencing of phonemes for production (Breen & Warrington, 1995). A common route to the POL shared by naming and reading cannot account for dissociations between semantic errors in naming and oral reading. Other mechanisms, unavailable during naming, must facilitate selection of a phonological entry in the POL during reading. Intact nonsemantic mechanisms assist in correct selection of a phonological entry during reading. Therefore, a central limitation of serial models of oral reading is their inability to account for dissociations across lexical tasks requiring the same cognitive subcomponents.

Alternative proposals have been put forward to account for dissociations across lexical tasks. These proposals postulate that cooperation occurs between the semantic and nonsemantic mechanisms during reading. To account for semantic errors during naming and their absence when reading Hillis and Caramazza (1991), in their ''Summation Hypothesis,'' proposed that sublexical GPC and semantic procedures function jointly to activate a phonological entry. They argue that semantic errors cannot occur with intact GPC. An intact GPC mechanism effectively ''blocks'' the production of semantic errors because it provides additional information that facilitates selection of the appropriate phonological entry. The GPC mechanism, in effect, generates the pronunciation of the word. Although arguing for summation at the POL the hypothesis follows the basic assumption that nonsemantic information will only influence phonological lexical access when semantic information is insufficient (Coltheart, 1987). The notion of cooperative mechanisms during oral reading has the benefit of accounting for differences in error patterns across different lexical tasks and allowing alternative sources to compensate for an impaired mechanism. These models can account for dissociations between naming and oral reading only when the other nonsemantic mechanisms are intact. For example, the ''Summation Hypothesis'' put forward by Hillis and Caramazza cannot account for dissociations in semantic errors between oral reading and picture naming if the GPC mechanism is impaired. If impaired GPC accompanies impaired lexical semantics, semantic errors cannot be ''blocked'' effectively. Therefore, we would predict that semantic errors should occur with the same frequency in both oral reading and picture naming. A regularity effect is also predicted by the ''Summation Hypothesis.'' If the GPC mechanism activates a phonological entry we would predict the least summation for irregular words (Breen & Warrington, 1995). Not all patients with deep dyslexia demonstrate a regularity effect. Therefore, modification of such nonserial models is necessary to account for possible dissociations in error performance when several reading mechanisms are impaired.

Other researchers argue that an independent GPC mechanism is not necessary to account for some errors in deep dyslexia (Kay & Marcel, 1981; Friedman & Kohn, 1990). In this alternative view, retrieval of phonological entries for both words and nonwords occurs by analogy. Oral reading of both words and nonwords utilizes phonological entries in a phonological lexicon (van Orden, 1987; Kay & Marcel, 1981; Friedman & Kohn, 1990). Nonwords activate phonologically similar real words that combine to provide the pronunciation of the nonword. Impaired access to the phonological lexicon affects the oral reading of both words and nonwords. If reading of words and nonwords occurs by analogy, error responses should always be phonologically similar to real words or, in the case of nonwords, close approximations of the target nonword. Deep dyslexic patients, however, do not always produce phonologically related errors. Further, if reading nonwords and words relies on accessing the POL and this mechanism is impaired similar errors should be present during spontaneous speech, picture naming, and repetition. As with serial dual-route models, reading by analogy fails to explain dissociations in error responses across a variety of oral production tasks, all of which access the POL.

We report the case of a deep dyslexic patient LC with marked dissociations in error patterns across a variety of lexical tasks. Current serial models of oral reading fail to account for such dissociations. We propose two hypotheses related to the organization and processing structure of the reading system. The first hypothesis concerns simultaneous activation of reading mechanisms. The second hypothesis relates to weightings given to each mechanism. First, we propose, as in standard models, that three functionally and conceptually independent routes are available for word reading: the semantic mechanism, the direct OIL to POL mechanism, and GPC procedures. However, a letter string activates simultaneously all three mechanisms. Information from these three mechanisms converges and integrates at the POL to constrain activation of an appropriate phonological entry. GPC information combines with semantic and direct nonsemantic information to select a phonological entry. The saliency of information from each mechanism dictates its influence on phonological selection. The mechanism with the most salient information has the strongest influence on phonological selection.

Integration of multiple sources of information at the POL is compatible with some models of word recognition (Venezky & Massaro, 1987, Massaro & Cohen, 1994). In these models, recognition of a word results from the integration of various sources of information over time (e.g., features of the graphic image, letters). All sources have some influence on word recognition. Integration involves uniting the various sources to yield a decision (word recognition). The contribution of sublexical sources relates inversely to the contribution of semantic information. Venezky and Massaro (1987) have shown that word recognition is based on the integration of information related to both orthographic structure and spelling to sound regularity. Therefore, we argue that correct pronunciation of a written word results from integration of information supplied by all three reading mechanisms to the POL. Integration of information at the POL will influence the error patterns observed in deep dyslexia, ultimately accounting for dissociations observed between oral reading and other oral production tasks.

Our second hypothesis relates to the impact each reading mechanism has on phonological selection with changes in task demands and the nature of the stimuli (Patterson & Coltheart, 1987). The mechanism with the most salient information will have the greatest impact or weighting. In many instances, this may be the semantic route. However, additional information supplied by the OIL to POL and GPC mechanisms will further constrain selection of a phonological entry. Variations in task demands and the nature of the stimuli will alter the relative weighting of each mechanism. For example, when reading nonwords the weighting of the GPC mechanism may be greater than weightings given to either the direct OIL to POL or semantic mechanisms. Irregular words, on the other hand, may require stronger weightings of the semantic and direct nonsemantic lexical mechanisms compared to the GPC mechanism. For function words, weightings for the nonsemantic routes might be stronger than the weight given to the semantic mechanism. Brain damage may alter the weightings of these different reading mechanisms. For example, if brain damage degrades semantic information the nonsemantic sources of information may become more or less important depending on their own integrity. Changes in weights for each mechanism may explain dissociations in error patterns across different kinds of words in deep dyslexics.

Normal readers can switch between reliance on lexical and sublexical reading mechanisms, suggesting that altering weightings based on the nature of the stimuli and task demands is plausible. Monsell, Patterson, Graham, Hughes, and Milroy (1992) showed that naming latency of nonwords was faster in blocks of nonwords than when mixed with exception words (e.g., have), reflecting a strategic shift from nonlexical to lexical pronunciation. Baluch and Besner (1991) demonstrated the opposite effect. They compared reading phonologically transparent (vowel included in the spelling) and phonologically opaque words (vowel is not specified) in Farsi. Word frequency effects were present for both classes of words when nonwords were absent from the list. Inclusion of nonwords in a list resulted in frequency effects for opaque words.

In this paper, we report investigations of a right-handed woman with deep dyslexia. We first interpret her reading impairment according to serial cognitive neuropsychological models of oral reading. We focussed on the nature of her errors and make inferences about the loci of her deficits within lexical semantics. We also analyzed extensively her errors during confrontation naming because it also involves visual analysis, access to semantics and the POL, and subsequent selection and sequencing of phonemes for oral production. If a patient has a deficit at any one of these stages, then similar errors should be evident across all tasks putatively mediated by these cognitive subsystems. Inconsistent performances across related tasks would signal the need to reconsider the original model. Thus, we aimed to test the adequacy of serial models of reading. Through extensive error analyses, we aimed to test our alternative hypotheses about the simultaneous influence of all three reading mechanisms on the POL.

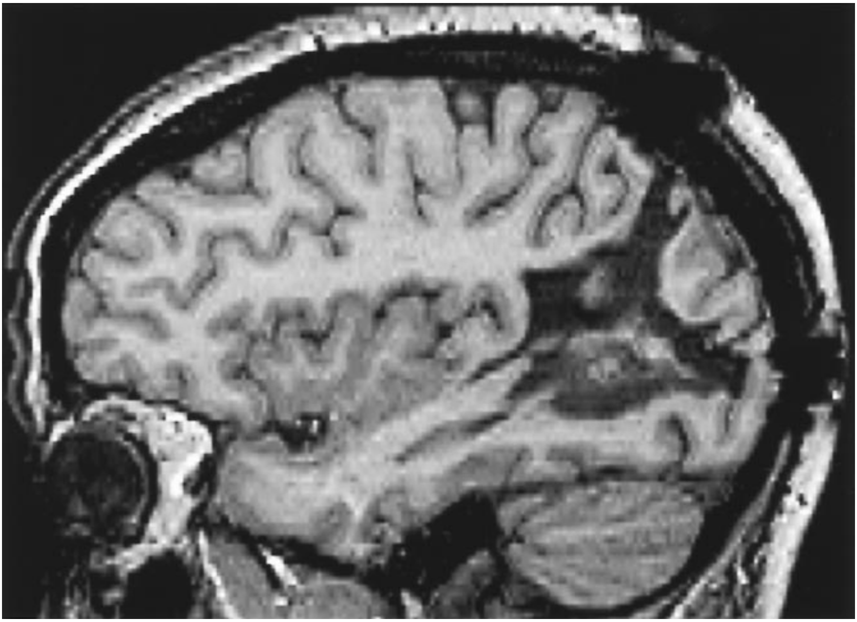

FIG. 1. Magnetic resonance imaging scan of LC's lesion obtained in July 1996.

CASE HISTORY

LC is a 34-year-old right-handed woman. She completed 2 years of college and was employed as a sales person prior to the development, in April 1996, of a left cerebral mycotic aneurysm involving the posterior division of the left middle cerebral artery. An initial CT scan revealed an intracerebral hematoma that was surgically removed. An MRI scan 5 months postonset showed an extensive lesion involving the posterior half of the middle temporal gyrus, most of the angular gyrus, part of the supramarginal gyrus and some of area 19. The lesion involved primarily the underlying white matter (see Fig. 1).

Western Aphasia Battery (Kertesz, 1982) results are shown in Table 1. In May (1996) her aphasia quotient was 36.44 and she was classified as being a Wernicke's aphasic. LC improved rapidly, at reevaluation in July 1996, her aphasia quotient was 85.8, and she was classified as having anomic aphasia.

Initial neuropsychological evaluation in July 1996 showed that LC had good concentration and spatial constructional skills. A memory disorder was evident for both visual and verbal information. Deficiencies were also apparent in her spelling and arithmetic skills. Digit span was reduced. She was able to repeat four digits forward and three backward. Language comprehen-

TABLE 1
Western Aphasia Battery Results

	May	July
Spontaneous speech		
Information content	4/10	8/10
Fluency	5/10	8/10
Comprehension		
Yes/no questions	42/60	60/60
Auditory word recognition	12/60	59/60
Sequential commands	2/80	67/80
Repetition	52/100	91/100
Naming		
Object naming	0/60	59/60
Word fluency	0/20	8/20
Sentence completion	8/10	8/10
Responsive speech	4/10	10/10
Reading		
Reading comprehension	0/40	20/40
Reading commands	0/20	20/20
Word–object matching	4/6	6/6
Word–picture matching	6/6	6/6

sion was impaired. On the Token Test (De Renzi & Faglioni, 1978) she responded correctly 12/22. On the sentence repetition test her performance was at the third percentile. As sentences became longer paraphasic errors increased. Word finding was deficient. She scored 48/60 on the Boston Naming Test (Goodglass, Kaplan, & Weintraub, 1983). Verbal Fluency was reduced. LC was only able to generate one word beginning with a particular letter in 1 min. Her capacity to learn new information across trials, such as on the California Verbal Learning Test, was poor with a maximal recall of 8/16 items after five learning trials. On the Wisconsin Card Sorting Test she was able to complete three trials while making 59 perseverative responses. Her reading comprehension fell at less than the first percentile for her age group. She was extremely slow in reading and inaccurate in answering the questions about the material that she read.

METHODS AND RESULTS

A series of tests were given to LC to determine if her oral reading deficit resulted from a disturbance to the OIL, the semantic system, the POL or due to impaired GPC. Our method and results are organized in the following manner. We first gave LC the *Battery of Adult Reading Function* (Gonzalez-Rothi, Coslett, & Heilman, 1984) to assist in identifying the nature of her reading deficit. Frequency and word length effects were evaluated. We then discuss results of LC's GPC and letter identification. The assessments of her phonologic and semantic systems follow. Finally, we discuss the nature of her errors produced during oral reading, naming, repetition, and spontaneous speech.

Oral Reading of Single Words

The *Battery of Adult Reading Function* (Gonzalez-Rothi et al., 1984) consists of nonwords, regular words, rule-governed words, irregular words, and function words. Each subtest contains 30 words. The regular and irregular word lists contained nouns, verbs, and adjectives. The overall average frequency of usage for these words was 43.7 per million with mean values of 43.3 for regular words and 43.8 for irregular words (Kucera & Francis, 1967). The average frequency of usage for function words was 403.3 (Kucera & Francis, 1967). The number of graphemes per word was balanced across the three lists with an average of 5.3 graphemes per word (range, 4–8). Nonwords were phonologically possible and probable (Kay & Marcel, 1981).

Oral reading regular words. LC read 40% of the regular words accurately. The majority or her errors (42%) were phonologically similar to the target (e.g., transfer → /trænspɚ/). Neologisms (e.g., mask → /speɪl/, inform → /zɪmp/) were produced frequently (38%). Neologisms often contained phonemes not found in the target word and their syllabic structure did not always correspond to that of the intended words. She also produced derivational errors (10%) (e.g., factor → factory, maker → make) and on two occasions she provided the definition of the word.

Oral reading rule-governed words. LC read 40% of the rule governed words accurately. Thirty-three percent of her errors were neologisms. Again, these neologisms showed little resemblance to the target words (e.g., ritual → /dɚst/), not even in the number of syllables. Of her remaining errors 24% were phonologic (e.g., beast → breast), 22% were semantic (e.g., wealth → rich), 11% were derivational (e.g., wrap → unwrap), and one word was not attempted.

Oral reading irregular words. She read accurately 50% of the irregular words. Most of her errors (65%) were neologisms that were phonologically dissimilar from the target word (e.g., menace → /æŋgli/; circuit → /nɪθik/. She produced a small proportion of phonologic (12%), semantic (12%), and derivational (6%) errors and one regularization error (e.g., corps → corpse).

Oral reading function words. LC's oral reading of function words was also poor (37%). Her pattern of error responses on this subtest differed markedly from that observed on the regular and irregular word lists. She read most function words (50%) incorrectly as other function words (e.g., else → already). Some function words (20%) were also read as other words (e.g., itself → special). Neologisms accounted for 15% of her errors. Of her errors, 15% were nonattempts.

Frequency effects. Word frequency also affects reading performance in patients with acquired dyslexia. Low frequency words would be more difficult to access and more susceptible to degradation than high frequency words (Friedman & Kohn, 1990). We would predict that high frequency words would have stronger representations and are less likely affected than low frequency words if the phonological system is impaired. To determine if her oral reading was influenced by word frequency LC read 20 low frequency words (0 to 6 per million, Mean = 2) and 20 high frequency words (99 to 897 per million, Mean = 253) (Snodgrass & Vanderwart, 1980). Word length was controlled. For both the high and low frequency words, 17 were one syllable in length and 3 were two syllables in length. LC read 17/20 (85%) of the high frequency words correctly. She produced three errors: one derivational (e.g., eye → eyes), one phonologic (e.g., hand → /hart/), and one unrelated word substitution (e.g., book → door). LC read 15/20 (75%) of the low frequency words correctly. Three of her errors were phonologic (e.g., sled → shed). The remaining two were neologisms (e.g., flute → /pilt/, blouse → /blɪm/).

Word length effects. Many researchers have argued that length will affect the oral reading abilities of patients with deep dyslexia (Coltheart, 1985). LC read a set of 114 one-, two-, and three-syllable words. Each syllable set contained 38 words. The accuracy of her reading decreased as the length of the word increased from one (79%) to two (58%) to three (55%) syllables. Of the eight errors produced when reading one-syllable words, four were phonologic errors (e.g., reel → /rim/), two were unrelated word substitutions (e.g., desk → Beth), and one was a neologism. The final error was a semantic error (e.g., web → spider). The pattern of errors differed for the two- and three-syllable words. Of the 16 errors produced for the two-syllable words 6 were neologisms (e.g., donkey → /dʒʌndi/; jealous → /wɛldʒəm/), 4 were derivational (e.g., raisin → raisins), 2 were unrelated word substitutions (e.g., machine → fascinate), 2 were semantic (e.g., nephew → niece), and 1 was phonologic (e.g., thunder → thumder). One word was not attempted. Error responses for the three-syllable words are as follows: neologisms (9/17), derivational (3/17), unrelated substitutions (2/17), semantic (2/17), and phonologic (1/17). As word length increased LC's oral reading deteriorated. The proportion of neologisms produced increased markedly with increases in word length.

Summary of findings. LC's reading of regular, rule-governed, irregular, and function words was poor. Most errors were neologisms or phonologic paralexias. Neologisms occurred most often when reading rule governed and irregular words. Phonologic paralexias were most frequent when reading regular words. Function words were often read as other function words. Word frequency did not effect her oral reading performance. As word length increased errors, particularly neologisms increased.

Grapheme to Phoneme Conversion

Oral reading nonwords. To evaluate GPC LC read aloud 30 nonwords. LC was unable to read accurately any of the nonwords. Forty-seven percent of her nonword errors did not resemble the target nonwords (e.g., trooge → /næŋ/; tralf → /θʌndʒ/). Thirteen percent of the nonwords were read as real words (e.g., slem → plum; crang → playing). Twenty-three percent of her nonword errors were phonologically similar to the target nonword (e.g., /ɪlɛndʒ/ → /ɪlɛnd/; /soʊg/ → /soʊd/). Definitions (e.g., pheke said 'like a snake,' 'scomb' said, ''like you do your hair'') were provided for 7% of the nonwords. LC did not attempt 10% of the nonwords. At times, LC attempted to either sound out the letter or spell the word to produce a correct response. When sounding out individual letters LC often produced the incorrect sound. Her inability to read nonwords may be attributable to a disruption of GPC.

Letter-to-sound conversion. This task was designed to verify that an inability to convert letters to sounds affected her oral reading ability. Each letter of the alphabet was printed on a 5 by 8-in. card and LC was instructed to say the sound corresponding to each letter. LC could only reproduce the sound corresponding to a letter 52.6% of the time. Error responses were not always closely related to the target sound (e.g., said /j/ → /k/; /i/ → /və/). On occasions she produced vowels sounds for consonant sounds (e.g., /f/ → /i/; /g/ → /ə/). The results show that LC's ability to apply grapheme-to-phoneme correspondence rules was impaired for single letters.

The Integrity of Letter Identification

Cross-case letter matching. A cross-case letter matching task assessed the integrity of abstract letter identification (Coltheart, 1987). All 26 letters of the alphabet were used. Each letter was printed in upper case on a single sheet of paper. LC was asked to identify, from all 26 letters printed randomly in lower case below, the letter. Accuracy was 100%.

Cross-case letter string matching. LC was given a cross-case letter string matching task to see if her oral reading deficit resulted from an inability to integrate letter strings. Three letters printed in upper case were presented on a sheet of paper. Her task was to identify the corresponding lower case letter string from a set of six. LC matched correctly 30/30 letter strings.

Summary of sublexical processing. Reading nonwords and letter to sound conversion was extremely poor, indicative of impaired GPC. LC's reading errors were not complicated by impaired abstract letter identification. Cross-case letter matching and cross-case letter string matching were intact.

Assessing the Integrity of the Orthographic Input Lexicon and the Phonological Output Lexicon

Orthographic lexical decision. To determine if LC could access the orthographic lexical forms from written input she performed a visual lexical decision task. A computer software program (SPARCS for Windows, Smith, 1994) displayed the written stimuli on a monitor. LC saw 150 words (30 nonwords, 30 regular, 30 rule governed, 30 irregular, and 30 function words) 1 at a time in random order. All stimuli were repeated to measure LC's reliability. LC was instructed to click the left mouse button if she thought the letter string she saw was a word. If she thought letter string presented was a nonword she was instructed to click the right mouse button. She was asked to respond to each item as quickly as possible. The computer recorded all her responses and her reaction times (RTs). RTs were measured from word onset.

Table 2 shows the percentage of correct scores and mean RTs for the reading lexical decision task. LC had little difficulty determining whether the letter string was a nonword or a word. LC judged all words, with the exception of one irregular word as words. Of the 30 nonwords 88% were judged correctly as nonwords. RTs for nonwords differed significantly from those for the word decisions [$F(1, 188) = 8.50$, $p < .004$]. No significant differences were observed across the RTs for the different word groups [$F(3, 236) = 2.1$, $p < .05$]. Computing a percentage agreement score assessed reliability. Agreement was 97.5% showing LC was reliable. She did not agree on three occasions for nonwords. On the first occasion, she judged the nonword as a word and on the second as a nonword. These results confirm that LC's ability to access the word form in the OIL.

Auditory lexical decision. LC performed well on an auditory lexical decision task using the same words as those in the orthographic lexical decision task. The same computer program was used to output the auditory stimuli. Percentage of correct scores and mean RTs are displayed Table 2. Accuracy

TABLE 2
Percentage Correct and Mean Reaction Times for the Auditory and Written Lexical Decision Tasks

Task	Nonwords	Regular words	Rule governed words	Irregular words	Function words
Reading					
% Correct	88	100	100	97	100
Mean RT	2.23	0.92	0.98	1.49	0.93
Auditory					
% Correct	77	100	100	100	100
Mean RT	1.54	0.67	0.59	0.66	0.81

of word judgments was 100%. She judged 23% of the nonwords as words. Her RTs for the nonword decisions differed significantly from the word decisions [$F(1, 118) = 45.92$ $p < .0001$]. RTs for nonwords tended to be slower than for words. No significant differences were observed across RTs for the four groups of words [$F(3, 236) = 1.9$, $p > .05$].

A percentage agreement score was computed to determine LC's reliability. LC was extremely reliable (100%), even for error responses. If she judged a nonword incorrectly as a word on the first occasion, she judged it as a nonword on the second occasion.

Picture/pseudohomophone matching. The results of the orthographic lexical decision task supports the notion that LC can access the OIL and that once accessed the lexicon is intact. However, it is possible that LC was performing some phonological recoding of the grapheme string that contributed to her ability to perform normal lexical access. A pseudohomophone picture matching task was used to determine if phonological recoding of graphemes assisted lexical access. LC was given 18 pseudohomophones and asked to choose from three pictures the one that matched the word. LC performed this task poorly achieving 33% correct. She chose pictures with written forms similar to the pseudohomophones (e.g., she chose the picture 'pray' for 'prarey,' 'yoke' for 'yott,' 'palace' for 'paleese,' 'nail' for 'niel'). Her error responses suggest attempts to employ a visual strategy to reconstruct the written word form to choose an appropriate response. The results confirmed that GPC did not aid lexical access.

Reading rhyme judgment. Rhyme judgments assess the ability to access phonological representations within the POL without the confounds of speech production (Friedman & Kohn, 1990). To determine if two written words rhyme the reader must first access stored orthographic representations and then their corresponding output phonological representations.

A computer program displayed 40 word pairs 1 at a time on a computer monitor. Ten were visually similar rhyming pairs (e.g., gown–town), 10 were visually similar nonrhyming pairs (e.g., hint–pint), 10 were visually nonsimilar rhyming pairs (e.g., dry–pie), and 10 were visually nonsimilar rhyming pairs (e.g., night–read). Each word pair was presented twice in random order. Instructions were given to click the left mouse button if the word pair rhymed and to click the right mouse button if the pair of words did not rhyme. LC was discouraged from reading any of the word pairs aloud. The computer recorded all responses as well as response times.

Table 3 shows that LC's reading rhyme judgment response times were relatively slow, ranging from 1.58 to 69.1 s. Her slower responses showed no relationship to any particular group of word pairs. She could accurately judge visually similar rhyming word pairs and visually nonsimilar nonrhyming word pairs. Her performance was poor when judging visually similar nonrhyming pairs (25%) and visually nonsimilar rhyming pairs (65%).

Her poor performance on the visually similar nonrhyming word pairs sug-

TABLE 3
Percentage Correct Scores for the Reading Rhyme Judgment Tasks

	Visually similar nonrhyming		Visually similar rhyming		Visually nonsimilar rhyming		Visually nonsimilar nonrhyming	
	%	Mean latency	%	Mean latency	%	Mean latency	%	Mean latency
Reading	25	13.17	100	10.59	65	18.98	100	15.08

gests that she used a visual strategy to determine if the words rhymed. If the words were visually similar, she considered the pairs to rhyme. LC's visual strategy in making rhyme judgments suggests an inability to construct phonology from orthography. That is, because of impaired access to the POL LC determined if words rhymed based on orthographic similarity.

Auditory rhyme judgment. The same words used in the reading rhyme judgment task were used. LC's auditory rhyme judgment performance was superior to her reading rhyme judgment (see Table 4). Accuracy was above 95% for both nonrhyming and rhyming word pairs. Mean auditory rhyme response latencies were considerably faster than her reading rhyme response latencies. Response latencies ranged from 0.31 to 6.34 s.

Summary of orthographic and phonological lexical access. Her performance on auditory and lexical decision tasks indicated that LC was capable of accessing the phonological input lexicon and the OIL. Orthographic lexical access was intact and could not account for her oral reading disturbance. Performance on the reading rhyme judgment task was poor compared to performance on the auditory rhyme judgment task. Performance on the reading rhyme judgment task suggests LC has difficulty accessing the POL. Her poor accuracy for visually similar nonrhyming pairs suggests decisions were based on a visual strategy.

Assessing the Integrity of the Semantic System

To assess semantic integrity LC performed a variety of tasks including picture–picture matching and word–word matching using the *Pyramids and Palm Trees Test* (PPTT) (Howard & Patterson, 1992). The PPTT tests se-

TABLE 4
Percentage of Correct Scores for the Auditory Rhyme Judgment Tasks

	Nonrhyming		Rhyming	
	% Correct	Mean latency	% Correct	Mean latency
Auditory	95	1.06	100	1.38

mantic access from words and pictures. This test of word association consists of 55 triads: three practice items and 52 test items. The task is to match the top item to one of two items printed below. LC, on two separate occasions, performed both the word and the picture matching tasks. To confirm that LC was capable of accessing semantics from the orthographic input lexicon she also performed a homophone picture matching task. Homophone picture matching is not aided by phonological lexical access.

Picture–picture matching. If a general semantic deficit influenced LC's oral reading ability we predicted that she would do poorly on the semantic associate test. Accuracy on the PPTT picture–picture matching task was 88%. A score of 90% indicates no impairment in semantic access. Lexical semantic access from picture stimuli was minimally impaired.

Word–word matching. This task assesses semantic from the OIL. We predicted that if LC was unable to access word meaning via the OIL she would perform poorly. Accuracy on word–word matching was 90%, indicating that no impairment to semantic access via the OIL.

Homophone picture matching task. LC was presented with 18 homophone word pairs (e.g., mail, male) and asked to identify the word that went with the picture. The word pairs were homophonic but no homographic. LC achieved 94% correct, again indicating that impaired lexical semantic access via the OIL could not account for the severity of LC's oral reading impairment. LC could access the meanings of words she was incapable of reading aloud.

Summary of semantic access. LC's performance on all tasks assessing semantic access was good. Impaired semantic access was not the basis of her poor oral reading.

Oral Reading PPTT, BNT, and ANT

A deficit in lexical semantic access cannot account for LC's poor oral reading. Part of her reading impairment might relate to an inability to access a phonological entry in the POL from appropriate semantic information. To assess phonological lexical access in the POL LC read words from the PPTT, the BNT (Goodglass et al., 1983), and the Action Naming Test (ANT) (Obler & Albert, 1982). LC read accurately 69% of the words on the PPTT test. Of her errors 42% were neologisms (e.g., caterpillar → /lɪləpɛpə/), 24% were phonologic (e.g., thimble → /sɪmbəl/), 8% were derivational (e.g., soldiers → soldier), and 13% were unrelated substitutions (e.g., puddle → pillow). She produced semantic errors 14% of the time. These unrelated substitutions might have been perseverative errors. LC had correctly read the word 'pillow' earlier in the test. She produced one semantic error (e.g., windmill → watermill).

LC read 67% of the words accurately on the BNT. Most reading errors on the BNT were neologisms (58%) followed by semantic errors (12.5%)

and unrelated word substitutions (12.5%). She produced few literal paralexias (4%) and derivational errors (4%). She did not respond 8% of the time. Her reading performance on the ANT was quite similar. Word reading accuracy was 62%. Most of her errors were neologisms (53%), followed by unrelated substitutions (21%). Sixteen percent of her errors were semantic followed by literal paralexias (5%) and no responses (5%).

Confrontation Naming

To establish that a general phonological deficit was responsible for her oral reading problem LC named in the PPTT, BNT, and ANT. Oral naming of the pictures in the PPTT was poorer than performance on picture–picture matching. She named only 46% of the pictures correctly. In contrast to her oral reading errors most of her naming errors (52%) were semantic associates or descriptions of the picture (e.g., saddle → horse). Her remaining errors included literal paraphasias (11%), derivational errors (12%), neologisms (11%), and unrelated word substitutions (14%).

LC named 23% of the pictures accurately on the BNT. Of her errors on the BNT 25% were semantic, 17% were neologisms, 6% were literal paraphasias, 2% were unrelated substitutions, and 23% she was unable to name. Picture naming accuracy on the ANT was 36%. On the ANT the majority of her errors (49%) were no responses, closely followed by semantic errors (41%). Only a few neologisms (3%) and unrelated substitutions (3%) were produced. The neologisms produced by LC when naming differed from those produced during oral reading. Many of her neologisms when naming pictures were target related. They often maintained the syllabic integrity and began with the same initial syllable as the target word. As mentioned previously neologisms produced when oral reading tended to be phonologically unrelated to the target word. Syllabic integrity and the initial phoneme were not maintained.

Repetition

To assess LC's repetition abilities and to determine if her error responses resembled those observed in oral reading LC repeated all words that had been used to evaluate her oral reading.

Repetition of nonwords. LC accurately repeated 70% of the nonwords. Five of her nine repetition errors were real words (e.g., birough → bureau, soud → sad, crang → crying) which suggest a lexicalization strategy. However, two of these errors (e.g., vyte → bite, vatter → batter) may have been paraphasic errors. Three of the errors were phonemic paraphasias (e.g., intret → /ɪntrɛk/; jisp → /dʒɛsp/) that differed from the target by only one distinctive feature (in this case, place). She produced one neologism (illend → /jand/).

Repetition of words. LC repeated all words correctly from the Battery of Adult Reading Function (Gonzalez-Rothi et al., 1984), with the exception of one function word. She produced one paraphasic error when repeating function words (thus → bus). No errors were produced when repeating words from the PPTT, BNT, or ANT. Repetition of words was far superior to her oral reading of the same words.

Spontaneous Speech

Samples of LC's spontaneous speech were collected. Analysis of LC's spontaneous speech would corroborate the possibility that poor reading performance resulted from a generalized phonological deficit. Samples were collected from spontaneous responses to questions, picture description and retelling the Cinderella story (see Appendix for examples). She produced only two literal paraphasias (/igə/ for ''evil'' and /əparp/ for ''apart'') during the production of 562 words.

Comparison of Oral Reading, Naming, Repetition, and Spontaneous Speech

To establish whether impaired phonological lexical access contributed to LC's oral reading deficit we compared her error performance across spontaneous speech, repetition, oral reading, and naming of the words on the PPTT, BNT, and ANT. By using the same test items across the different tasks we avoided the possible confound of differences in error responses due to differences in target responses. If a general phonological deficit was the cause of LC's oral reading problem we would predict that her error responses should be qualitatively similar across these tasks. Figure 2 shows the proportion of errors produced by LC when reading aloud and during picture naming of the PPTT. Repetition is not shown as LC produced no errors. The numbers of errors produced in naming and reading were not the same. Computation of error proportions allowed comparison of error patterns across tasks. During picture naming on the PPTT 52% of her errors were semantic in contrast to 14% when oral reading. She produced almost four times as many neologisms when reading than when naming. When reading she also produce twice as many phonologic errors than when naming. The difference in errors between naming and oral reading is also evident for the BNT (Fig. 3). LC produced twice as many semantic errors when naming than when reading. The dissociation in errors is particularly apparent for neologisms. This dissociation between neologisms when naming and oral reading is very striking on the ANT (Fig. 4). The proportion of semantic errors when naming was almost four times greater than when reading. The difference in error patterns becomes even more marked for spontaneous speech and repetition. Neologisms were absent in LC's spontaneous speech and literal paraphasias were minimal (2).

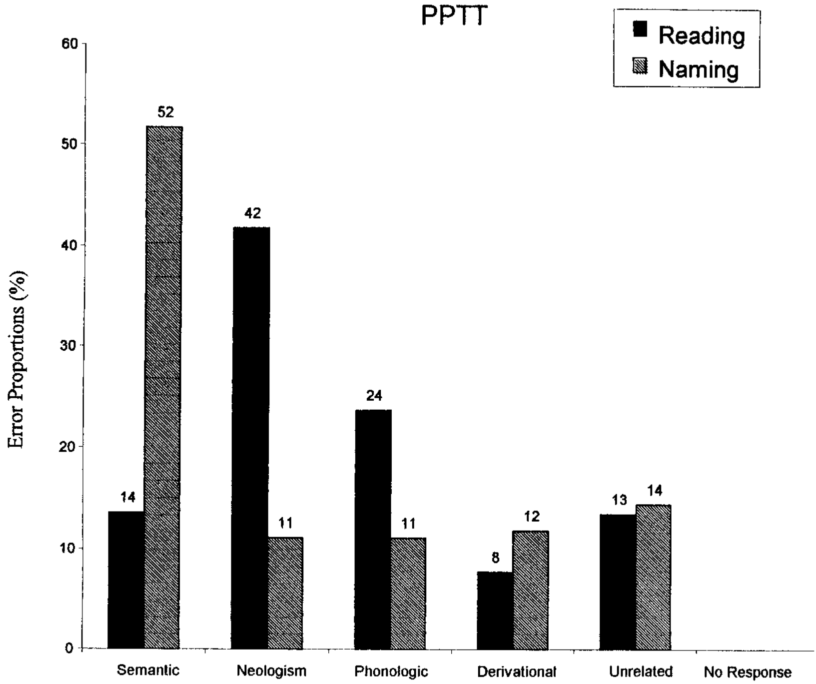

FIG. 2. Proportion of errors (%) produced by LC when reading words and naming pictures from the Pyramids and Palm Trees Test (PPTT).

Marked word finding errors were apparent in LC's spontaneous speech. During repetition, LC produced no errors on the same material read or named.

Summary. Comparison of reading, naming, spontaneous speech, and repetition show marked differences in error patterns across these lexical tasks. Neologisms and phonologic paralexias were most prominent when oral reading. Semantic errors prevailed during picture naming. Neologisms were absent in spontaneous speech. A serial model of oral reading cannot readily explain these marked dissociations in error patterns.

DISCUSSION

LC presented with deep dyslexia. She was unable read any nonwords. Oral reading of regular, rule-governed, irregular, and function words was poor. On average 14% of her reading errors were semantic. Word frequency did not effect her oral reading. Reading performance deteriorated as word length increased. Cross-case letter and syllable matching showed that early visual disturbances or poor letter identification did not affect her oral reading. Word–word and picture–picture matching tasks verified relatively normal semantic access. Picture–word–homophone matching tasks also indicated

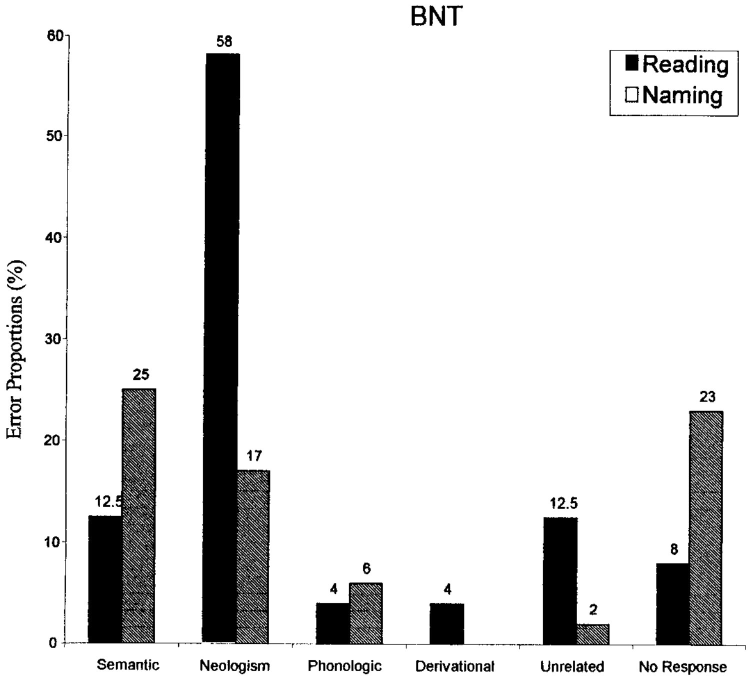

FIG. 3. Proportion of errors (%) produced by LC when reading words and naming pictures from the Boston Naming Test (BNT).

preserved lexical semantic access. Poor reading rhyme judgments showed an inability to access the POL from the OIL. Poor pseudohomophone–picture matching showed an inability to access the POL via GPC. Oral confrontation naming was poor. Repetition of words was intact.

Most of LC's reading errors were either neologisms or phonological paralexias. She also produced semantic errors when reading aloud. Function words were read frequently as other function words. Oral reading errors differed markedly from those observed in picture naming, spontaneous speech, and repetition. Most naming errors were semantic associates or descriptions of the picture with few literal paraphasias or neologisms. Although word finding difficulties were apparent in spontaneous speech she produced few literal paraphasias and neologisms were absent. Repetition of words was error free. Serial models cannot adequately explain the dissociation in error patterns across these different lexical tasks. If deep dyslexics read via the semantic route with minimal cooperation from the other nonsemantic routes then LC's reading errors should be quantitatively and qualitatively similar to those in naming, spontaneous speech, and repetition.

A simultaneous activation hypothesis readily explains differences in error patterns across different lexical tasks. Figure 5 shows a basic oral reading

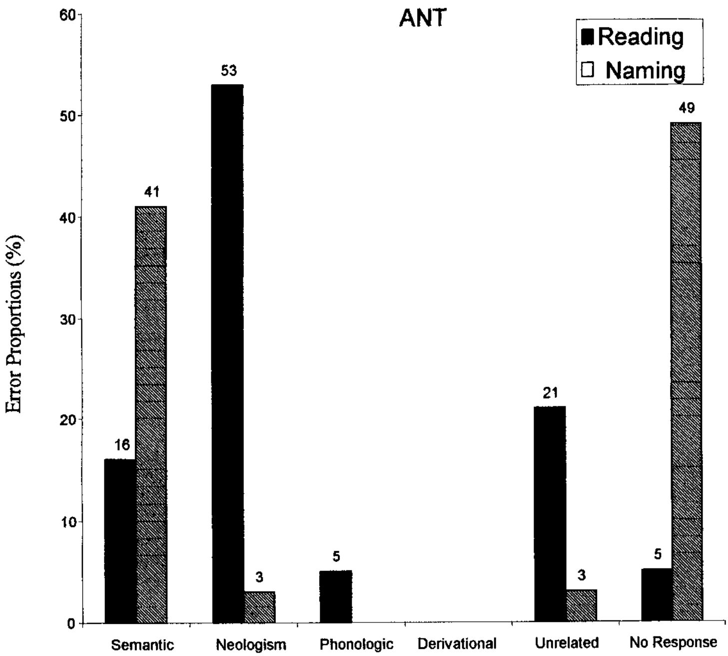

FIG. 4. Proportion of errors (%) produced by LC when reading words and naming pictures from the Action Naming Test (ANT).

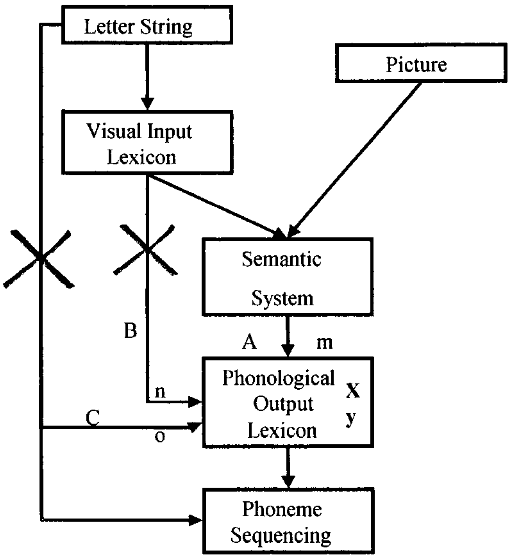

FIG. 5. Model of processes involved in oral reading.

model that we will use to explain our simultaneous activation hypothesis. To review, three independent reading mechanisms, the semantic mechanism (A), the direct OIL to POL mechanism (B), and the GPC mechanism (C), activate simultaneously when a letter string is encountered. Information from these mechanisms integrate at the POL to constrain selection of the correct phonological entry (X). Therefore, during oral reading the weightings for A, B, and C yield X, or $A+B+C \rightarrow X$. In naming and spontaneous speech, activation of the phonological entry X occurs because the semantic route (m) is maximally weighted. Weights for the direct OIL to POL (n) and GPC (o) mechanisms are minimal or zero. Therefore, when naming or speaking X is activated primarily by the weighting given to m or $m \cong X$ and $n + o \cong 0$. Because a maximal weight is given to m to activate X during naming and spontaneous speech, $m \neq A$. Importantly, the weighting given to semantics to activate a phonological entry in the POL will vary depending on task demands and the nature of the stimuli. We will discuss the different error responses based on this model. We will first discuss the basis of LC's semantic errors, neologisms, and phonological errors. Additional evidence for integration of information from the three reading mechanisms at the POL will follow.

Semantic Errors

Because LC produced semantic errors in oral reading, naming, and spontaneous speech, all of which require semantic access, the logical conclusion would be that LC's semantic errors arise from degradation to the semantic system. However, she did well on the PPTT. Constraints imposed by simple picture–picture and word–word matching tasks may not expose degradation to the semantic system. The constraints provided by these tasks might facilitate activation of a complete semantic representation. Production tasks that minimize these constraints may elucidate the underlying basis of this semantic deficit. LC either had a subtle semantic deficit or one of semantic egress.

Degradation to the semantic system will cause an inability to retrieve either the appropriate semantic concept or a complete semantic representation (Friedman & Perlman, 1982; Marshall & Newcombe, 1966). With the former error, one word (e.g., spider) may arouse a similar semantic concept (e.g., web). If unable to retrieve a complete semantic representation superordinate errors (e.g., bird for eagle) or shared feature words (coordinate errors, e.g., hurt for injure) should be produced (Friedman & Perlman, 1982; Marshall & Newcombe, 1973). LC's semantic errors were the substitution of words with shared semantic features or superordinate errors. The nature of her errors suggests a degradation of the semantic system. Therefore, the POL receives an incorrect or impoverished semantic representation and activates a phonological entry for that representation. Based on the assumption that reading and naming share a common serial organization through the semantic system the frequency of semantic errors should be quantitatively similar across these different lexical tasks if other routes are not available for reading. This was not the case for LC. Semantic errors were much more frequent during naming than in oral reading (see Figs. 2, 3, and 4). Further, LC read a large number of words that she was unable to name.

Differences in Semantic Errors during Oral Reading and Naming

A simultaneous activation model readily accounts for differences between semantic error proportions in oral reading and naming and LC's ability to read words that she could not name. Returning to Fig. 5, the general principle of serial models is that oral reading is constrained by maximal weighting of the semantic system (A) with minimal weighting of B and C. Accessing a semantic representation during naming also occurs through maximal weighting of semantics (m in Fig. 5). A similar inability to read and name words would mean that the weight of A would be equivalent to that of m, given that B and C are almost zero. However, LC read a large number of words that she could not name and the proportion of semantic errors in naming was three to four times greater than when reading. This pattern suggests that weighting of A and m are not similar, or A $\neq m$. During oral reading, the POL is constrained by B and C as well as A. Weightings given to B and C as well as A activate to threshold the correct phonological entry (X) in the POL, even when semantic information is degraded. During naming n and o are zero, allowing no additional information to assist in the activation of the correct phonological entry, increasing the likelihood of semantic errors. Degraded semantic information supplied to the POL results in the production of a semantic associate (y). Therefore, in naming m activates y instead of X.

Neologisms

LC made many neologisms when reading. Damage to the OIL and semantic access cannot account for her neologisms in oral reading because her performance on lexical decision, picture–picture, and word–word matching tasks was good. Based on a serial model of oral reading neologisms should arise from impaired access to the POL from the semantic system. If neologisms arise from impaired phonological access they should also appear in spontaneous speech and picture naming. The absence of neologisms in LC's spontaneous speech mitigates impaired access to the POL as the cause.

Our model can account for the presence of neologisms in LC's oral reading and their absence in her spontaneous speech. During reading a correct phonological entry is activated through the integration of multiple sources of information at the POL (weightings given to A, B, and C in Fig. 5). In the case of LC, for some words the POL receives impoverished information from all three reading mechanisms. This impoverished information increases the ambiguity in the selection of a correct phonological entry (X), reducing the probability that one will achieve threshold (t). Therefore, weightings of A, B, and C will not yield X(t). Consequently, a random sequence of phonemes is selected for production resulting in a nontarget related neologism. LC produced a large number of neologisms unrelated to the target in syllabic structure and initial phoneme. In some instances, the neologisms contained no sounds associated with the target. Our hypothesis also accounts readily for the absence of neologisms during spontaneous speech and repetition. During these tasks, impoverished information from the direct OIL to POL and GPC mechanisms cannot integrate with salient or partial semantic information at the POL because weights for *n* and *o* are almost zero. Degraded or partial semantic information feeds forward via *m* to the POL, more likely causing a semantic error.

Phonological errors

LC produced a large proportion of phonological errors when reading regular words (58%). Literal paraphasias were almost nonexistent in naming (7%) and spontaneous speech (less than 1%). They were completely absent in repetition. Caplan (1993) argues that literal paraphasias occur at the level of selection and sequencing of phonemes after accessing a complete phonological representation in the POL. We cannot attribute LC's phonemic paralexias to this level. If she had an additional deficit in selection and sequencing of phonemes, we would anticipate similar phonological errors in repetition and spontaneous speech. Garrett (1992) argues that paraphasic errors occur when selected lexical targets contact output phonological entries that are unstable or minimally degraded. We know that LC's output phonological entries are relatively stable as verified by her ability to read words that she could not name. Current models of reading with a serial organization of multiple levels of processing fail to explain differences in the proportion of phonological errors across oral reading, spontaneous speech, and naming.

Accounting for the greater proportion of phonological errors in oral reading compared to other production tasks requires the notion of simultaneous activation of the three oral reading mechanisms. We have established that in many instances LC's semantic representations are impoverished. These impoverished semantic representations feed forward to the POL. The POL also receives partial information from both B (the direct OIL to POL mechanism) and C (GPC) because they are also weighted. This additional information, although somewhat impoverished, integrates with degraded semantic information at the POL. The partial alternative mappings funneled through B and C allows a partial representation of the correct phonological entry to reach threshold. Therefore, in oral reading weightings applied to A, B, and C will yield an approximation of X. This partial phonological entry is available for further processing at the phoneme sequencing level. On the other hand, when naming only the semantic mechanism (*m*) activates a phonological entry. The POL receives impoverished semantic representations through *m* activating a semantic associate (*y*) of the target phonological entry. Therefore, in naming *m* gives rise to *y* instead of X. This notion accounts for phonologically plausible errors when reading both nonwords and words.

Additional Evidence for Convergence at the POL

A simultaneous activation hypothesis can also account for errors produced when reading nonwords and function words as well as length effects. LC's performance on these tasks provides additional evidence that the POL receives input from all three reading mechanisms simultaneously.

Nonword errors. On some occasions LC read nonwords as words or provided a definition of a word for a nonword. Integration of multiple sources of information at the POL can account for such errors. We argue that encountering a nonword letter string also activates visually similar words in the OIL. For example, the letter string ''scomb'' activates the word ''comb'' in the OIL. This information is then sent via the direct nonsemantic (OIL to POL) and semantic routes to the POL. GPC also sends information to the POL. Information received at the POL is sufficient to activate an entry in the POL that is phonologically similar to the nonword. In the case of semantic descriptions, we argue that information from the OIL is sufficient to activate a partial semantic representation. However, weights given to B and C are insufficient to assist in activating to threshold a phonological entry. The production of nonwords as words invites the conclusion that these nonwords elicit simultaneous activation of words in the OIL, potentially activating to threshold a phonological entry in the POL.

Function word errors. A common observation in deep dyslexia is that many function words are read as other function words. This pattern of errors differs from other kinds of words read. Therefore, information from the different reading routes may differ in value depending on the word read. Massaro and Cohen (1994) argue that the source of information that has the most value will have the greatest impact on phonological selection. Based on this assumption we propose that each reading mechanism might be represented in the form of weighted alternatives. That is, although activated simultaneously the three reading mechanisms are not equally weighted for all kinds of words. For example, $A \neq B \neq C$ for function words. Morton and Patterson (1980) argue that the semantic route is insufficient for reading function words. Therefore, in order to constrain activation of a function word at the POL the direct OIL to POL mechanism (B) and GPC mechanism (C) may be more strongly weighted than the semantic mechanism (A). In this instance $B = C \neq A$. For example, when reading function words B and C may each be given a weight of 40, whereas A might be given a weight of 20 in order to activate a phonological entry. This would seem plausible in light of the fact that function words inherently contain very little semantic information. Different weightings for different mechanisms, appears a plausible assumption based on the findings that normal readers can switch from one mechanism to another depending on task demands (Baluch & Besner, 1991).

Length effects. A simultaneous activation model readily accommodates length effects. The number of LC's neologisms increased as word length increased, being most frequent for three-syllable words. Phonological errors were frequent when reading one-syllable words but were almost absent when reading two and three syllable words. Ambiguity of information from GPC and OIL to POL is more likely to increase with increases in word length. Therefore, information received at the POL about X from B and C is highly ambiguous. Increases in ambiguity of information with increases in word length reduce the probability that activation of any phonological entry will reach threshold within the POL. Increases in the ambiguity of information results in a reduction of constraints on phoneme selection and sequencing. Therefore, highly ambiguous information received at the POL about both the phonemes and the syllable structure of the target word may cause a neologism. With monosyllabic words it is likely that additional information received at the POL from the GPC mechanism and the direct OIL to POL mechanism is sufficient to activate (at least partially) a phonological entry. Therefore, with monosyllabic words the likelihood that phonological errors are produced increases.

CONCLUSION

We propose that a letter string activates three reading mechanisms simultaneously. Each reading mechanism is relatively independent and can be selectively impaired after brain damage. However, they are not functionally encapsulated in the traditional sense (Fodor, 1983). Information from these mechanisms integrates at the level of the POL. Although simultaneous activation of these mechanisms occurs, they are not weighted equally. The least ambiguous source of information has the largest influence.

Current serial cognitive neuropsychological models of oral reading cannot explain parsimoniously differences in error patterns across different lexical tasks in patients with deep dyslexia. A simultaneous activation model of oral reading accounts for such differences. When reading is impaired, partial information from both the nonsemantic routes interacts with impoverished semantic information at the POL. Therefore, the probability of activating a phonological entry decreases, resulting in a large number of neologisms. In other circumstances, information may be sufficient to activate a partial phonological representation causing phonological errors. Integration of information from the nonlexical reading routes with semantic information cannot occur during picture naming or spontaneous speech. Therefore, the POL only receives degraded semantic information increasing the probability of a semantic error. Differences in error patterns force us to postulate that the influence of different routes on the POL may vary depending on the nature of the stimuli and task demands.

APPENDIX: SPONTANEOUS SPEECH SAMPLES

Response to Questions

Can you tell me what happened to you?

What happened to me . . . I know that um . . . I hurt myself . . . a day after the day one of the days that I was in there . . . I was there seeing my . . . a gentleman I'm with and that night I hurt myself with um . . . with the doctor

Can you tell me what happened after that?

after I hurt . . . myself . . . a lot of different things happened . . . I started out real slow I didn't understand a single thing and as things have come on . . . I've understood that things have happened to me. A lot of things now as I understand things but I can't under . . . but I can't tell you guys what's going on . . . I mean I understand a lot of things and I can talk to things by myself or think about em but I can't tell you about em. . .

What did you do before your stroke?

At the moment I was not at work. I just moved from what I was doing before and I went to . . . I can't remember the name of it. We just recently moved and I was looking for a new job and at the time I was looking for that and for a job when this came /ʹparp/ (apart) when this came apart.

Picture Description

Well obviously they've their cookies there. Mom's there she she has a problem. I guess it looks like it poured over but um . . . nobody seems to recognize it and no one else seems to care about it. The little girl—she's looking for cookies but she doesn't have any cookies there . . . but she's looking for cookies . . . she wants cookies and this has been turned over . . . she's like she's turned over too. You know the thing that's been turned over . . . So she hasn't done . . . they have cookies there to eat. . .

The mother hasn't done it she doesn't care either . . . it looks like . . . like she's just sitting there with the water turned w . . . has turned over OK and she's just walking over it. I know this water's turned over . . . but. . .

Retelling the Cinderella Story

In the beginning was Cinderella. She now lives with her evil step mother and two sisters. What happened is the /igʹl/ (evil) bad mother did not treat her very well . . . The bad mother and her evil stepsisters were allowed to go. She was not allowed to go. Her feelings were hurt.

REFERENCES

Baluch, B., & Besner, D. 1991. Visual word recognition: Evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **17,** 644–652.

Beauvois, M. F, & Derouesne, J. 1979. Phonological dyslexia: Three dissociations. *Journal of Neurology, Neurosurgery and Psychiatry,* **42,** 1115–1124.

Breen, K., & Warrington, E. K. 1994. A study of anomia: Evidence for a distinction between nominal and propositional language. *Cortex,* **30,** 231–245.

Breen, K., & Warrington, E. K. 1995. Impaired naming and preserved reading: A complete dissociation. *Cortex,* **31,** 583–588.

Brown, P., & Besner, D. 1987. The assembly of phonology in oral reading: A new model. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading.* London; Lawrence Erlbaum.

Bub, D., Cancelliere, A., & Kertesz, A. 1985. Whole-word and analytic translation of spelling-to-sound in a non-semantic reader. In K. E. Patterson, J. C. Marshall & M. Coltheart (Eds.), *Surface dyslexia.* London: Lawrence Erlbaum.

Caplan, D. 1993. *Language: Structure, processing & disorders.* Cambridge: MIT Press.

Caramazza, A., Berndt, R. S., & Basili, A. G. 1983. The selective impairment of phonological processing: A case study. *Brain and Language,* **18,** 128–174.

Coltheart, M. 1980. Deep dyslexia: A review of they syndrome. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Coltheart, M. 1985. Cognitive neuropsychology and the study of reading. In M. I. Posner & G. S. M. Marin (Eds.), *Attention and Performance XI.* Hillsdale, NJ: Lawrence Erlbaum.

Coltheart, M. 1987. Functional architecture of the language processing system. In M. Coltheart, G. Sartori & R. Job (Eds.), *Cognitive neuropsychology of language.* Hillsdale, NJ: Lawrence Erlbaum.

De Renzi, E., & di Pellegrino, G. 1995. Sparing of verbs and preserved, but ineffectual reading in a patient with impaired word production. *Cortex,* **31,** 619–636.

De Renzi, E., & Faglioni, P. 1978. Normative data and screening power of a shortened version of the token test. *Cortex,* **14,** 41–49.

Ellis, A. W. 1984. *Reading, writing and dyslexia: A cognitive analysis.* London: Lawrence Erlbaum.

Ellis, A. W., & Young, A. W. 1988. *Human cognitive neuropsychology.* London: Lawrence Erlbaum.

Fodor, J. A. 1983. *The modularity of mind.* Cambridge, MA: MIT Press.

Friedman, R. B., & Kohn, S. E. 1990. Impaired activation of the phonological lexicon: Effects upon oral reading. *Brain and Language,* **38,** 278–297.

Friedman, R. B., & Perlman, M. B. 1982. On the underlying causes of semantic paralexias in a patient with deep dyslexia. *Neuropsychologia,* **20,** 559–568.

Funnell, E. 1983. Phonological processes in reading: New evidence from acquired dyslexia. *British Journal of Psychology,* **74,** 159–180.

Garrett, M. 1992. Disorders of lexical selection. *Cognition,* **42,** 143–180.

Goldblum, M.-C. 1985. Word comprehension in surface dyslexia. In K. E. Patterson, M. Coltheart & J. C. Marshall (Eds.), *Surface dyslexia.* London: Lawrence Erlbaum.

Gonzalez-Rothi, L. J. Coslett, H. B. & Heilman, K. M. 1984. *Battery of adult reading function.* (Experimental Edition)

Goodglass, H., Kaplan, E., & Weintraub, S. 1983. *The Boston naming test.* Philadelphia: Lea & Febiger.

Henderson, L. 1982. *Orthography and word recognition in reading.* San Diego: Academic Press.

Hillis, A. E., & Caramazza, A. 1991. Mechanisms for accessing lexical representation for output: Evidence from a category specific semantic deficit. *Brain and Language,* **40,** 106–144.

Howard, D., & Patterson, K. 1992. *The pyramids and palm trees test.* Suffolk: Thames Valley Test Company.

Kay, J., & Marcel, A. J. 1981. One process, not two, in reading aloud: Lexical analogies do the work of non-lexical rules. *Quarterly Journal of Experimental Psychology A,* **33,** 387–413.

Kertesz, A. 1979. *The western aphasia battery.* New York: The Psychological Corporation, Harcourt Brace Jovanovich.

Kucera, H., & Francis, W. N. 1967. *Computational analysis of present-day American English* Providence, RI: Brown Univ. Press.

Marshall, J. C., & Newcombe, F. 1966. Syntactic and semantic errors in paralexia. *Neuropsychologia,* **4,** 169–176.

Marshall, J. C., & Newcombe, F. 1973. Patterns of paralexias: A psycholinguistic approach. *Journal of Psycholinguistic Research,* **2,** 175–199.

Massaro, D. W., & Cohen M. M. 1994. Visual, orthographic, phonological and lexical influences in reading. *Journal of Experimental Psychology: Human Perception and Performance,* **20,** 1107–1128.

McCann, R. S., & Besner, D. 1987. Reading pseudohomophones: Implications for models of pronunciation assembly and the locus of word frequency effects in naming. *Journal of Experimental Psychology: Human Perception and Performance,* **13,** 13–24.

Miceli, G., Capasso, R., & Caramazza, A. 1994. The interactions of lexical and sublexical processes in reading, writing and repetition. *Neuropsychologia,* **32,** 317–333.

Monsell, S., Patterson, K. E., Graham, A., Hughes, C. H., & Milroy, R. 1992. Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **18,** 452–467.

Morton, J., & Patterson, K. 1980. A new attempt at an interpretation, or, an attempt at a new interpretation. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Newcombe, F., & Marshall, J. C. 1980a. Response monitoring and response blocking in deep dyslexia. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Newcombe, F., & Marshall, J. C. 1980b. Transcoding and lexical stabilization in deep dyslexia. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Nolan, K. A., & Caramazza, A. 1982. Modality-independent impairments in word processing in a deep dyslexia patient. *Brain and Language,* **16,** 237–264.

Norris, D. G., & Brown, G. D. A. 1985. Race models and analogy theories: A dead heat? Reply to Seidenberg. *Cognition,* **28,** 155–168.

Obler, L. K., & Albert, M. L. 1982. *The action naming test.* Boston, MA: VA Medical Center.

Patterson, K. E. 1978. Phonemic dyslexia: errors of meaning and the meaning of errors. *Quarterly Journal of Experimental Psychology,* **30,** 587–607.

Patterson, K. E. 1982. The relationship between reading and phonological coding: Further neuropsychological observations. In A. Ellis (Ed.), *Normality and pathology in cognitive functions.* New York: Academic Press.

Patterson, K. E., & Coltheart, V. 1987. Phonological processes in reading: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading.* London: Lawrence Erlbaum.

Patterson, K. E., & Morton, J. 1985. From orthography to phonology: An attempt at an old interpretation. In K. E. Patterson, J. C. Marshall & M. Coltheart (Eds.), *Surface dyslexia.* London: Lawrence Erlbaum.

Sartori, G., Masterson, J., & Job, R. 1987. Direct route reading and the locus of lexical decision. In M. Coltheart, G. Sartori & R. Job (Eds.), *Cognitive neuropsychology of language.* London: Lawrence Erlbaum.

Schwartz, M. F. 1987. Patterns of speech production deficit within and across aphasia syndromes: Application of a psycholinguistic model. In M. Coltheart, G. Sartori & R. Job (Eds.), *The cognitive neuropsychology of language.* Hillsdale, NJ: Lawrence Erlbaum.

Schwartz, M. F., Saffran, E., & Marin, O. S. M. 1980. Fractionating the reading process in dementia: Evidence for word-specific print-to-sound associations. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Shallice, T., & Warrington, E. K. 1980. Single and multiple component central dyslexic syndromes. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Smith, S. C. 1994. *SPARCS for Windows.* Computer software, University of Alabama at Birmingham.

Snodgrass, J. G., & Vanderwart, M. 1980. A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory,* **6,** 174–215.

Van Orden, G. C 1987. A ROWS is a ROSE: Spelling, sound, and reading. *Memory and Cognition,* **10,** 434–442.

Venezky, R. L., & Massaro, D. 1987. Orthographic structure and spelling-sound regularity in reading English. In D. A. Allport, D. G. MacKay, W. Prinz & E. Scheerer (Eds.), *Language, perception and production: Shared mechanisms in listening, speaking, reading, and writing.* London: Academic Press.