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The Interaction of Multiple Routes in Oral Reading: Evidence from Dissociations in Naming and Oral Reading in Phonological Dyslexia

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During oral reading we hypothesized that lexical representations are activated and selected for output by the simultaneous activation of the semantic, the direct lexical orthography to phonology, and the sublexical grapheme-to-phoneme conversion (GPC) routes (Southwood & Chatterjee, 1999). Serial models of reading argue that the semantic route governs oral reading with minimal influence from the nonlexical direct route and the sublexical GPC route. These models predict that semantic errors should occur in reading when the semantic route and GPC are both impaired. The Simultaneous Activation Hypothesis predicts few semantic errors in oral reading but many during picture naming. Semantic errors are infrequent in reading because information from all three reading routes constrains activation of a phonological entry. By contrast phonological selection in picture naming is constrained primarily by the semantic route and if damaged additional information is unavailable to select the appropriate phonological code. In agreement with the Simultaneous Activation Hypothesis five phonological dyslexics produced semantic errors during picture naming but not when reading aloud. Phonological errors were present during oral reading and minimal during picture naming.

INTRODUCTION

The cognitive neuropsychological approach has postulated three functionally independent reading routes in our cognitive architecture. Experienced readers rely on both lexical and sublexical processes when activating a pho-

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nological entry in the phonological output lexicon (POL) (see Fig. 1). Activation of a phonological entry in the POL occurs indirectly from the orthographic input lexicon (OIL) via lexical semantics (route A). Direct activation of a phonological entry from the OIL is the second lexical route available to the reader (route B). A sublexical procedure that converts letters to sounds (route C) allows reading of unfamiliar words and nonwords. Selective impairment of these modules after brain damage has lead to the idea that reading modules are independent and do not interact. Word reading occurs serially either via the semantic system or via grapheme-to-phoneme conversion (GPC) but not both (Massaro & Cohen, 1994). In this paper, we assess the adequacy of serial models of oral reading by examining the types of errors made by a group of phonological dyslexics.

Not all serial models incorporate all three possible routes in reading. Traditional dual-route theorists argue that reading takes place either via the semantic system or by GPC (Ellis & Young, 1988). However, GPC only comes into play with slowed semantic processing (Ellis & Young, 1988; Coltheart, 1987). The postulation of a sublexical GPC route is based on the ability of normal readers to read nonwords or unfamiliar words for which they have no representation in the POL (Coltheart, 1987). The unique reading disorder phonological dyslexia has bolstered the notion of an independent reading-specific sublexical GPC route. The inability to pronounce novel letter strings (in the absence of accompanying language deficits) is phonological dyslexia in its purest form (Beauvois & Derouesne, 1979). Unfortunately, isolated instances of phonological dyslexia are extremely rare. Many phonological dyslexics present with associated aphasic deficits such as disturbances in naming (Orpwood & Warrington, 1995; Farah, Stowe, & Levinson, 1996). If an associated semantic deficit accompanied GPC deficits dual-route models would predict that these patients should produce semantic errors in reading, as reading would take place via an impaired semantic route. These patients would be classified as having deep dyslexia, a syndrome in which patients cannot read nonwords and make semantic and phonological errors when reading real words. Traditional dual-route models would not predict that phonological dyslexics would make semantic errors in naming.

In analogy models, a variant of serial models, retrieval of phonological entries for both words and nonwords occurs by analogy. These theorists do not include a reading-specific route dedicated to GPC (Farah, Stowe, & Levinson, 1996; Friedman & Kohn, 1990). However, they do include a direct lexical OIL to POL route. Oral reading of both words and nonwords uses the phonological lexicon (van Orden, 1987; Kay & Marcel, 1981; Friedman & Kohn, 1990). Reading involves an indirect lexical route via semantics and a direct whole-word route. The direct word route is the principal mechanism for both word and nonword reading. In analogy models, phonological dyslexia arises from disruption to the direct whole-word route. Impairment to this reading mechanism forces phonological dyslexics to read nonwords via the indirect semantic route. Inaccurate nonword reading occurs because these letter strings lack semantic representations. A deficiency in the direct whole-word route also predicts a selective impairment of function words because of their limited semantic representations (Friedman, 1995; Morton & Patterson, 1980). However, some phonological dyslexics are not deficient in function word reading (Friedman, 1995; Friedman & Kohn, 1990; Bub, Black, Howell, & Kertesz, 1987; Funnell, 1983). If semantics is impaired patients can still read via the direct word route. For these patients the deficit lies at the level of the POL. Based on these models patients with impaired GPC and impaired semantics (based on naming tasks) should also make semantic errors in reading, resulting in a classification of deep dyslexia rather than phonological dyslexia.

We reported previously dissociations between naming and reading in a deep dyslexic patient, LC (Southwood & Chatterjee, 1999). LC produced numerous neologisms and literal paralexias during oral reading. These errors were almost absent in picture naming, spontaneous speech, and repetition. Semantic errors were frequent during spontaneous speech and picture naming but less frequent in oral reading. Current serial neuropsychological models of oral reading do not account for these dissociations. We introduced the notion of interaction between lexical and sublexical processes to account for differences in error patterns across different lexical tasks by suggesting that alternative sources of information compensate for impaired mechanisms. We based this Simultaneous Activation Hypothesis on the assumption that constraining a phonological entry in the POL during reading requires not only input from the semantic route but also other reading routes. Inputs to the POL from the sublexical GPC and the direct lexical OIL to POL routes provide additional information that activate the appropriate phonological entry despite the presence of a semantic deficit. These additional constraints mitigate the production of semantic errors during oral reading.

Figure 1 reviews the Simultaneous Activation Hypothesis. When a letter string is encountered independent sources of information from the semantic route (A in Fig. 1), the direct OIL to POL route (B in Fig. 1), and the GPC route (C in Fig. 1) activate simultaneously. Information from all routes interacts at the POL to constrain selection of the correct phonological entry (X). The combined weightings for A, B, and C activate X during oral reading. Information from each of these routes is not equally weighted. The weightings given to these routes will vary depending on the nature of the task and the stimuli read. Conversely, to activate a phonological entry during naming and spontaneous speech the semantic route (m in Fig. 1) gets maximal weighting, or $m \cong X$. The direct OIL to POL (n in Fig. 1) and GPC (o in Fig. 1) routes provide little if any information. These two routes are weighted minimally during picture naming and spontaneous speech or $n + o \cong 0$. Because m gets maximal weighting to activate X during naming and spontaneous speech but not during reading, m cannot equal A.

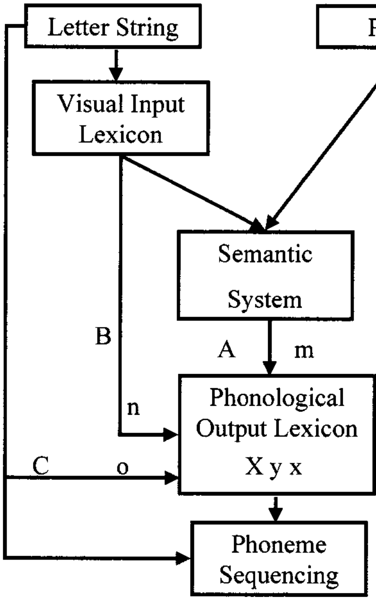

FIG. 1. A model of oral reading.

In this paper, we extend the Simultaneous Activation Hypothesis by assessing error patterns associated with phonological dyslexia. We provide data on five phonological dyslexics, all presenting with an associated semantic deficit. Current serial neuropsychological and analogy models of reading would predict that these patients would make semantic errors when reading. In contrast, the Simultaneous Activation Hypothesis does not predict semantic errors in reading despite such errors in naming tasks. Analogy models might also predict that these patients might have a more general phonological deficit causing the phonological dyslexia. If a phonological deficit caused phonological dyslexia then phonological errors should be apparent in all tasks requiring the same cognitive processes. Phonological errors should arise in naming, repetition, and spontaneous speech as well as during reading. The Simultaneous Activation Hypothesis, on the other hand, predicts that phonological dyslexics do not necessarily have a generalized phonological deficit.

CASE HISTORIES

We present the cases of five patients, four women and one man, with left cerebrovascular accidents (CVAs) (see Table 1 for site of lesion). Patient LC was the same subject we presented in a previous publication (Southwood & Chatterjee, 1999). LC on initial evaluation, presented with deep dyslexia. Reevaluation 8 months later revealed that she had progressed to a phonologic

TABLE 1
Case Histories

Subjects	Age (years)	Lesion	Diagnosis
LC	34	L supramarginal and angular gyrus	Phonologic dyslexic/anomic aphasic
VA	40	L parietooccipital	Phonologic dyslexic/anomic aphasic
VD	42	L posterior cerebral artery	Phonologic dyslexic/anomic aphasic
NS	63	L frontoparietal	Phonologic dyslexic/anomic aphasic
SE	29	L superior angular gyrus	Phonologic dyslexic/anomic aphasic

dyslexic. The patients ranged in age from 29 to 63 years ($M = 41.6$ years). All patients were right-handed. The Western Aphasia Battery (WAB) (Kertesz, 1982) was administered to all subjects. Their aphasia quotients, spontaneous speech, comprehension, repetition, naming, and reading scores from the WAB are displayed in Table 2. Aphasia quotients ranged from 70.2 to 87.9. All patients were relatively fluent, with adequate auditory comprehension. Spontaneous speech contained word-finding errors. Repetition was relatively intact. Word fluency was poor. Reading comprehension was relatively intact for three patients. The remaining two patients showed moderate reading comprehension deficits. WAB scores classified all patients as having an anomic aphasia.

TABLE 2
Western Aphasia Battery Results

	LC	VA	VD	NS	SE
Aphasia quotient	85.80	77.30	75.40	70.20	87.90
Spontaneous speech					
Information content	8/10	6/10	8/10	5/10	9/10
Fluency	8/10	6/10	8/10	5/10	9/10
Comprehension					
Yes/no questions	60/60	59/60	59/60	60/60	59/60
Word recognition	59/60	60/60	54/60	50/60	60/60
Sequential commands	67/80	70/80	53/80	66/80	72/80
Repetition	91/100	86/100	96/100	88/100	80/100
Naming					
Object naming	59/60	60/60	20/60	53/60	56/60
Word fluency	8/20	8/20	0/20	4/20	8/20
Sentence completion	8/10	8/10	10/10	8/10	10/10
Responsive speech	10/10	10/10	8/10	10/10	10/10
Reading					
Comprehension	20/40	32/40	4/40	32/40	32/40
Reading commands	20/20	15/20	15/20	10/20	20/20
Word–object matching	6/6	6/6	5/6	6/6	6/6
Picture matching	6/6	6/6	6/6	6/6	6/6

METHOD AND RESULTS

A series of tests were given to each patient to determine whether their oral reading deficits resulted from a disturbance to the OIL, the semantic system, or the POL or were due to impaired GPC. Our method and results are organized in the following manner. We first gave the Battery of Adult Reading Function (Gonzalez-Rothi, Coslett, & Heilman, 1984) to assist in identifying the nature of their reading deficits. Evaluation of frequency and word length effects follows. We then evaluated GPC and letter identification. Assessments of their phonologic and semantic systems follow. Finally, we discuss the nature of their errors produced during oral reading, naming, and spontaneous speech.

ORAL READING SINGLE WORDS

In order to assess reading performance all patients were administered the complete Battery of Adult Reading Function (Gonzalez-Rothi, Coslett, & Heilman, 1984). Each subtest contains 30 regular (e.g., sink), rule-governed (e.g., beast), irregular (e.g., aisle), and function (e.g., though) words. All 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 five lists, averaging 5.3 graphemes per word (range = 4–8). Nonwords were phonologically possible and probable (Kay & Marcel, 1981). Table 3 shows the percentage correct scores for each subtest on the Battery of Adult Reading Function (Gonzalez-Rothi et al., 1984). Oral word reading was superior to nonword reading. For words percentage correct scores ranged from 60 to 100%. Accuracy for regular words ranged from 80 to 97%. Score for rule-governed words ranged from 70 to 100%. Accuracy for irregular words ranged from 73 to 100% and for function words 60 to 93%. Nonword reading scores ranged from 7 to 43%.

Errors were classified as (1) semantic—production of a word related in meaning to the target (e.g., ankle → knee); (2) neologisms—production of a nonword using a randomly ordered string of phonemes (e.g., caterpillar

TABLE 3
Percentage Correct Scores for Each Subject for Reading and Repetition (in Parentheses) of the *Battery of Adult Reading Function* (Gonzalez-Rothi, Coslett, & Heilman, 1984)

Subject	Nonwords	Regular words	Rule-governed words	Irregular words	Function words
LC	43 (100)	97 (100)	93 (100)	100 (100)	93 (100)
VA	7 (100)	80 (98)	70 (98)	73 (100)	60 (100)
VD	10 (100)	97 (100)	100 (100)	73 (100)	83 (100)
NS	40 (93)	80 (100)	90 (100)	83 (97)	93 (93)
SE	7 (63)	87 (100)	73 (100)	80 (93)	90 (97)

→ /lɪləpɛpə/; (3) derivational—production of a word with the same free morpheme but with a different bound morpheme (e.g., carrot → carrots); (4) phonologic—errors bearing a phonological relationship to the target (e.g., thimble → /sɪmbəl/; (5) visually/phonologically similar words—word errors that were visually or phonologically similar to the target (e.g., sign → sigh; (6) Unrelated words—words that have no phonological relationship to the target word (e.g., though → specialty); and (7) no response.

When reading words, error responses were similar for regular, rule-governed, and irregular words. Error patterns when reading function words and nonwords differed. In order to compare error patterns, we computed error proportions because of differences in the frequencies of errors produced by the subjects. Figure 2 shows that phonological errors were frequent, with error proportions ranging from 30 to 56%. The proportion of neologisms was small. Error proportions for derivational errors ranged from 6 to 35%. The derivational errors produced by these patients involved inflectional operations (e.g., ''trees'' for ''tree''). An inflectional ending was either omitted or added. These patients did not produce errors on words involving derivational operations (e.g., pity–pitiful; marry–marriage). Unrelated word proportions ranged from 17 to 48%.

Figure 3 shows the pattern of errors produced by all subjects when reading function words. Most subjects substituted another function word (9–100%) or an unrelated word (33–70%). Most of the function words in the reading battery are auxiliaries with few prepositions. The function words substituted

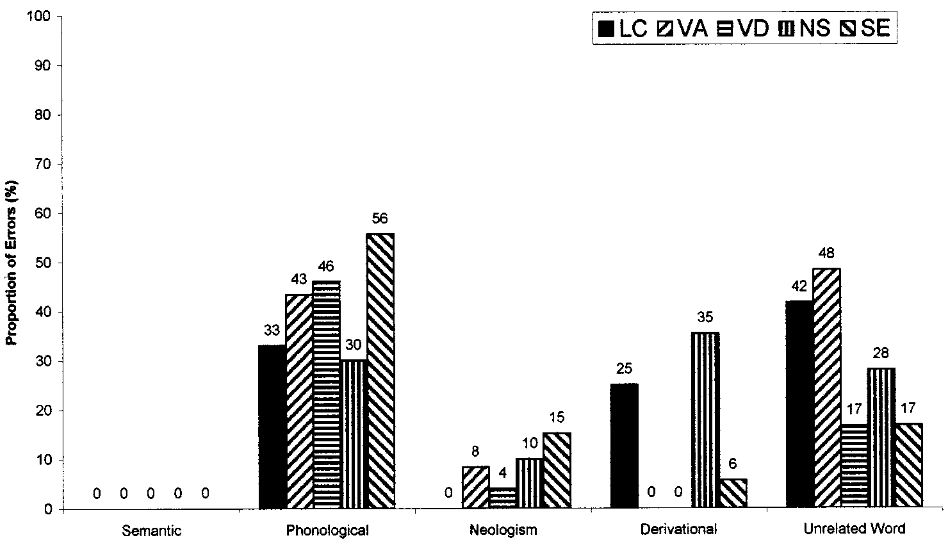

FIG. 2. Mean proportion of errors (%) produced by five phonological dyslexics when reading regular, rule-governed, and irregular words.

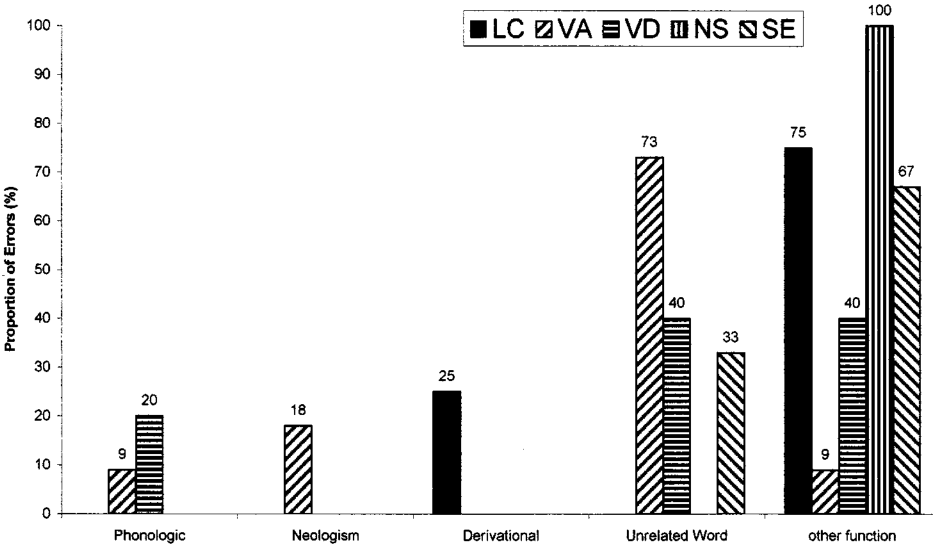

FIG. 3. Proportion of errors (%) produced by five phonological dyslexics when reading function words.

for target function words were also auxiliaries (e.g., ‘‘both’’ for ‘‘most’’). We could not determine if differences in errors for function words varied with the semantic information carried (e.g., prepositions versus auxiliaries) because the patients made no errors on the few prepositions in the function word subtest. One subject (VA) produced a large proportion of other word substitutions (e.g., ‘‘aisle’’ for ‘‘else’’). The proportions of neologisms (9–20%) and phonological (18%) and derivational (25%) errors were trivial.

Length and frequency effects. To evaluate length the patients read 114 one-, two-, and three-syllable words. Each syllable set contained 38 words. Table 4 shows the percentage of correct scores from the length and frequency

TABLE 4
Percentage Correct Scores for Oral Reading Length and Frequency Subtests

	Length (syallables)			Frequency	
Subject	1	2	3	High	Low
LC[a]	92	97	89	95	95
VA[a]	90	95	95	90	75
VD[a]	95	90	90	100	100
NS[a]	95	95	100	100	100
SE[a]	90	70	60	100	95

[a] Repetition of frequency and length subtests was above 97%.

subtests. Four of the five patients did not demonstrate a length effect. For these patients scores ranged from 89 to 100%. Patient SE showed a increase in error with increases in word length (see Table 4). Error responses produced during the length subtest mirrored those observed when reading the Battery of Adult Reading Function (Gonzalez-Rothi et al., 1984).

Word frequency effects were assessed by having the subjects read 20 low-frequency words (0 to 6 per million, Mean = 2) and 20 high-frequency words (99–897 per million, Mean = 253) (Snodgrass & Vanderwart, 1980). Table 4 also shows the percentage of correct scores for this subtest. There was no frequency effect for four of the five patients. For these patients scores ranged from 95 to 100%. Patient VA demonstrated a frequency effect, having a poorer score for low (75%)-than high (90%)-frequency words. Again, error types were similar to previous error responses.

Summary. All patients had difficulty reading. Word reading was superior to nonword reading. Semantic errors were absent. These results lead to the classification of phonological dyslexia. The most frequent errors produced when reading regular, rule-governed, and irregular words were phonologic errors and unrelated words followed by derivational errors. Word substitutions produced when reading function words differed from word substitutions for regular, rule-governed, or irregular words. Patients frequently substituted other function words for the target word. In contrast, substitutions for words were often unrelated to the target. Length and frequency tended not to affect reading performance.

GRAPHEME-TO-PHONEME CONVERSION

Oral reading nonwords and pseudohomophones. Nonword reading was substantially poorer than word reading for all patients. Percentage correct scores ranged from 7 to 43% (see Table 3). Figure 4 shows that a sizable proportion (35 to 69%) of nonwords were read as visually/phonologically similar words (e.g., ‘‘trade’’ for ‘‘trad’’). Phonological errors were numerous, with error proportions ranging from 15 to 53%. Neologisms were less frequent, with ranges from 4 to 32%. Nonresponses were infrequent (4 to 12%).

To evaluate further the ability to use GPC subjects read 35 pseudohomophones (e.g., ‘‘blud’’ for ‘‘blood’’). There are no representations for pseudohomophones in the OIL. Accessing the phonological entry for a pseudohomophone in the POL requires phonological recording of letters into sounds. Percentage correct scores ranged from 6 to 72%. Error rates in reading pseudohomophones were similar to nonword reading error rates for three patients. Two patients (VD and SE) demonstrated superior pseudohomophone reading to nonword reading. Error patterns were similar to those observed for nonword reading. Visually/phonologically similar words frequently replaced the pseudohomophones (35 to 72%). Neologisms were relatively prominent (5 to 42%) followed by unrelated words (5 to 10%) or no response (6 to 10%).

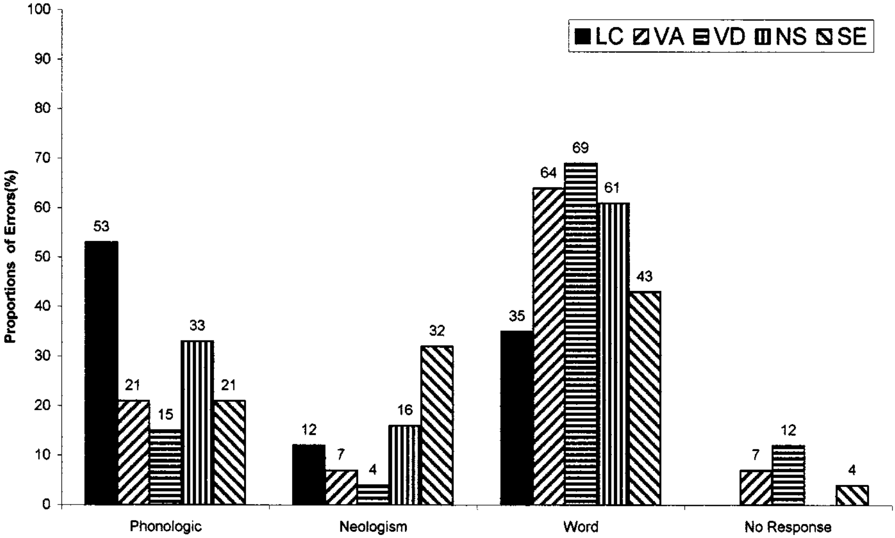

FIG. 4. Proportion of errors (%) produced by five phonological dyslexics when reading nonwords.

Letter-to-sound conversion. This task assessed letter-to-sound conversion. Each letter of the alphabet was printed on a 5- by 8-in. card. The patient said the sound corresponding to each letter. All subjects performed poorly on this task. Scores ranged from 0 to 74%.

Summary. Reading nonwords and pseudohomophones was poor, indicating impaired GPC. Most errors were visually/phonologically similar words or neologisms. Poor letter-to-sound conversion confirmed impaired GPC.

THE INTEGRITY OF LETTER IDENTIFICATION

Cross-case letter matching. The integrity of abstract letter identification was assessed with cross-case letter matching (Coltheart, 1987). Each letter of the alphabet was printed in uppercase on a single sheet of paper. Patients identified each letter, from all 26 letters printed randomly in lowercase below the letter. Accuracy was 100% for all patients.

Cross-case letter string matching. To evaluate integration of letter strings the patients performed a cross-case letter string matching task. Subjects were given 30 three-letter strings, each printed in uppercase on a sheet of paper. Subjects chose the letter string from a set of 6 lowercase strings printed below. All patients matched accurately all letter strings.

Naming letters. To confirm that subjects could identify letters accurately they were asked to name the letters of the alphabet, presented in random order. Accuracy was 100% for all patients, affirming intact letter identification.

Summary. Cross-case letter matching tasks showed clearly that visual processes required for letter identification were intact. Poor visual processing did not contribute to their reading deficits.

ASSESSING THE INTEGRITY OF THE ORTHOGRAPHIC INPUT LEXICON AND THE PHONOLOGICAL OUTPUT LEXICON

Lexical decision. To determine if the patients could access orthographic lexical forms from written input, they performed a nontimed visual lexical decision task. Table 5 shows that accuracy of nonword identification ranged from 78 to 93%. Accuracy of word identification was good for four of the five patients, ranging from 80 to 100%. VD had some difficulty identifying irregular words (60%). Auditory lexical decision scores were similar, with nonword scores ranging from 86 to 90% and word judgments ranging from 80 to 100% (see Table 5).

Rhyme judgment. Rhyme judgments assess the ability to access phonological representations within the POL. Readers must first access stored orthographic representations and then their corresponding output phonological representations to make the appropriate comparisons. Forty pairs of rhyming words were administered, of which 10 were visually similar nonrhyming (e.g., hint–pint), 10 were visually similar rhyming (e.g., town–gown), 10 were visually nonsimilar rhyming (e.g., dry–pie), and 10 were visually nonsimilar nonrhyming (e.g., tail–roll). Without reading aloud the subjects judged if the word pairs rhymed. Table 6 shows that rhyme judgments scores for visually similar nonrhyming pairs ranged from 50 to 80%. For the visually similar rhyming pairs scores ranged from 80 to 100%. For four of the five patients scores ranged from 80 to 100% for the visually nonsimilar rhyming pairs. Patient SE had difficulty identifying visually nonsimilar rhyming pairs (60%). Visually nonsimilar nonrhyming pairs were identified most accurately, with scores ranging from 90–100%. Performance on an auditory rhyme judgment task using the same stimuli ranged from 95 to 100%.

TABLE 5
Reading and Auditory Lexical Decision Scores

	Nonword		Regular		Rule-governed		Irregular		Function	
Ss	Read	Audit	Read	Audit	Read	Audit	Read	Audit	Read	Audit
LC	93	86	100	100	100	98	100	98	100	100
VA	83	87	80	100	80	90	80	80	80	90
VD	93	90	90	100	80	80	60	80	100	90
NS	78	87	100	100	100	90	90	90	90	100
SE	80	90	100	90	100	80	90	80	100	80

TABLE 6
Written Rhyme Judgment Scores

Subject	Visually similar nonrhyming	Visually similar rhyming	Visually nonsimilar rhyming	Visually nonsimilar nonrhyming
LC[a]	50	100	100	100
VA[a]	60	100	80	100
VD[a]	70	80	80	100
NS[b]	80	100	90	100
SE[a]	80	90	60	90

[a] 100% correct on auditory rhyme judgment.
[b] 95% correct on auditory rhyme judgment.

Summary. The scores for visual lexical decision tasks suggest that all patients, with the exception of VD, could access the OIL. Patient VD had difficulty identifying irregular words. All patients had difficulty judging visually similar nonrhyming word pairs. Poor written rhyme judgments showed that all patients had some difficulty with phonological lexical access from the OIL.

ASSESSING THE INTEGRITY OF THE SEMANTIC SYSTEM

Picture–picture matching and word–word matching using the Pyramids and Palm Trees Test (PPTT) (Howard & Patterson, 1992) assessed semantic access. The PPTT is a test of semantic association consisting of 55 triads: 3 practice items and 52 test items. The top item in the triad is matched to 1 of 2 items printed below. Patients performed both the word and picture matching tasks on two separate occasions. We assessed semantic access via the OIL further using a homophone–picture matching task because phonological lexical access does not aid homophone–picture matching. Eighteen homophone pairs (e.g., mail, male) were presented to each subject. Each homophone pair was printed below a picture. The task required identification of the word matching the picture. The word pairs were homophonic but not homographic. Pseudohomophone–picture matching was used to determine if semantic access was available through the POL via GPC. The pseudohomophone was printed below three pictures. Each subject chose the picture that matched the pseudohomophone. To determine if subjects could access the semantic system through the POL via GPC a pseudohomophone–picture matching task was employed. The results of these tasks are displayed in Table 6.

Picture–picture matching. Picture–picture matching scores ranged from 69 to 100% (see Table 7). Scores above 90% indicate intact semantic access. Lexical semantic access on this task was intact for LC and SE. Semantic access deficits were apparent for patients VA, VD, and NS.

TABLE 7

Percentage Correct Scores for Picture–Picture and Word–Word Matching on the *Pyramids and Palm Trees Test* (Howard & Patterson (1992), Homophone Matching, and Pseudohomophone Matching

Subject	Semantic access picture/picture	Semantic access word/word	Homophone matching	Pseudohomophone matching
LC	100	90	100	78
VA	83	85	94	44
VD	69	40	71	57
NS	77	79	76	50
SE	92	96	100	49

Word–word matching. Results for this tasks were similar to the picture–picture matching task. Scores ranged form 40 to 96% (see Table 7). Both LC and SE had intact semantic access via the OIL. Semantic access from OIL was deficient for the other three patients, particularly VD. Semantic access for VD was markedly poorer for word–word matching than for picture–picture matching.

Homophone–picture matching task. Scores ranged from 71 to 100% (see Table 7), confirming deficits in semantic access from the OIL for patients VD and NS.

Picture/pseudohomophone matching. A pseudohomophone–picture matching task was used to determine if phonological recording of graphemes assisted lexical access. In this task, semantic access occurs by accessing the POL via GPC. All subjects had difficulty with this task. Scores ranged from 44 to 78% (see Table 7). Poor pseudohomophone matching is indicative of an inability to access the POL and ultimately semantics through GPC.

Summary. The results evaluating semantic integrity show that patients LC and SE demonstrated intact semantic access. The remaining three patients (VA, VD, and NS) had difficulty accessing semantics from either a visual stimulus or the OIL.

COMPARISON OF ORAL READING, NAMING, REPETITION, AND SPONTANEOUS SPEECH

Oral reading PPTT. Theorists (Friedman & Kohn, 1990) argue that phonological dyslexia may arise from an inability to access a phonological entry in the POL. To assess phonological lexical access in the POL the patients read the words from the PPTT (Howard & Patterson, 1992). The results in Table 8 show that oral reading performance on the PPTT was superior to semantic access via words for most subjects. Scores ranged from 83 to 98%. In particular, VD had very poor semantic access from words (40%). However, he was capable of reading many of the words that he could not comprehend (90%). Figure 5 displays the proportion of errors produced when read-

TABLE 8
Percentage Correct Scores for Picture Naming and Oral Reading from the PPTT (Howard & Patterson (1992)

Subject	Naming pictures	Oral reading
LC	83	92
VA	67	83
VD	31	90
NS	60	93
SE	83	90

ing and naming from the PPTT. The figure shows frequent phonological and derivational errors and neologisms when reading. With the exception of NS, semantic errors were absent (see Fig. 5, top). NS produced only five errors when reading the PPTT, one of which was a semantic error.

Picture naming. To establish if a general phonological deficit was responsible for their oral reading problems the patients also named the pictures in the PPTT. All subjects were poorer at naming pictures than reading the PPTT words (see Table 8). Naming scores ranged from 31 to 83%. There tended to be marked individual differences within and across patients between semantic access tasks and naming. Picture naming was poorer than semantic access for VD, in particular, and VA and NS (see Table 7). Semantic errors were the most frequent error produced by all subjects when naming pictures (see Fig. 5, bottom). Furthermore, when naming VA, VD, and SE did not attempt to self-correct their errors. The lack of self-corrections and their poor picture–picture matching scores suggest that their naming errors were due to poor semantic access or degradation to the semantic system. The number of nonresponses produced by these three patients partly supports the notion of semantic degradation rather than lexical access problems. LC occasionally attempted to self-correct her naming errors, which in part supports the notion that her naming deficit relates to a semantic egress problem.

Comparison of oral reading and naming errors. To establish whether impaired phonological lexical access contributed to their oral reading deficit we compared their error performance across oral reading and naming of the words and pictures in the PPTT. By using the same target items across the different tasks we avoided the possible confound of differences in error responses due to different targets. All response were transcribed phonetically and analyzed according to the criteria used for analysis of error responses on the Battery of Adult Reading Function (Gonzalez-Rothi et al., 1984). If semantics alone constrains both reading and naming we would predict that quantitatively and qualitatively similar errors should occur in both tasks. Table 8 shows that oral reading performance was superior to picture naming

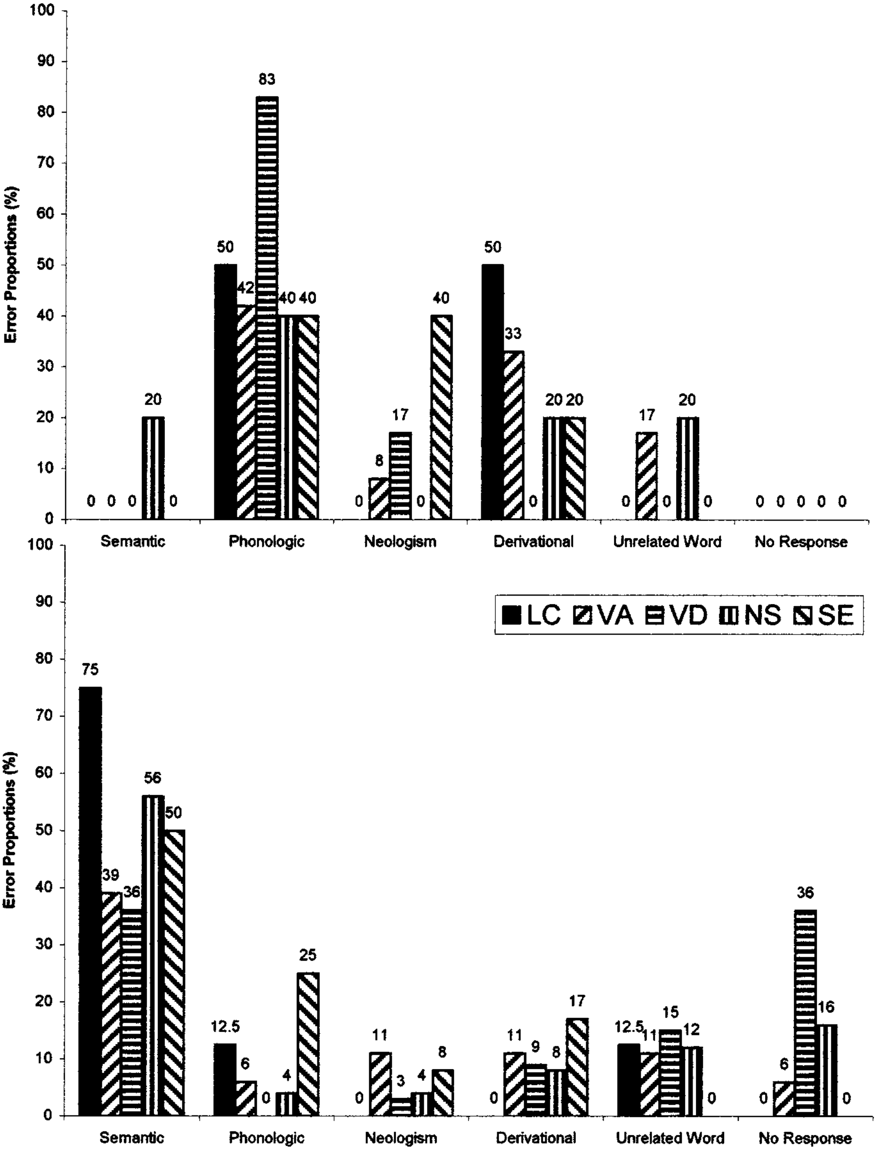

FIG. 5. Proportions of errors (%) produced by five phonological dyslexics when reading words from the PPTT (top) and when naming pictures from the PPTT (bottom).

performance. The superiority of oral reading over picture naming is particularly evident for VD.

From Fig. 5 we can see a clear-cut dissociation between the proportion of semantic errors produced in reading and naming. Four of the five subjects did not produce any semantic errors when reading orally. The opposite dissociation was observed for phonological errors. Four of the five subjects produced three or more times as many phonological errors when reading than when naming. This dissociation between semantic errors and phonological errors is also apparent in spontaneous speech, with all subjects producing word-finding problems in the absence of phonological errors and neologisms.

Repetition. Subjects repeated the words from the Battery of Adult Reading Function (Gonzalez-Rothi et al., 1984) and the PPTT. With the exception of SE, all subjects repeated all words and nonwords accurately. SE had difficulty repeating nonwords (63%), substituting phonologically similar words. Patients repeated accurately the pseudohomophone stimuli they could not read. Repetition was free of semantic errors and phonological errors were trivial.

Spontaneous speech. Appendix A provides examples of spontaneous speech. Analysis of spontaneous speech might corroborate the possibility that poor oral reading resulted from a generalized phonological deficit. From the spontaneous speech samples, it was apparent that each subject had word-finding problems. However, none of the subjects produced any literal paraphasias or neologisms when speaking. The absence of literal paraphasias and neologisms in spontaneous speech suggest that the POL is relatively intact.

Summary. The results showed a marked disparity in the errors produced in oral reading compared to those produced in other speech production tasks. Phonological and derivational errors and neologisms were prominent during oral reading. Semantic errors were profuse during picture naming. Repetition of words was flawless. With the exception of SE, repetition of nonwords was above 93% for all subjects. Neologisms and derivational and phonological errors were absent during spontaneous speech.

DISCUSSION

We summarize below the performance of the five patients on lexical and nonlexical processing tasks. Nonword reading was disproportionately poorer than word reading. This dissociation provides clear evidence of inefficient grapheme-to-phoneme conversion. Semantic errors were absent during oral reading; hence, all patients were classified as phonological dyslexics. Patients often substituted visually or phonologically similar words for nonwords. Small proportions of nonword errors were neologisms. Other nonwords produced phonological errors. Word errors included phonological and derivational errors, neologisms, or substitutions of unrelated words.

Cross-case letter matching and syllable matching showed adequate early visual processes. Word–word and picture–picture association tasks showed deficiencies in semantic access for three patients. Semantic access was intact for two of the patients. With the exception of VD, all patients made lexical decisions accurately indicating intact access to the OIL. Poor rhyme judgment scores for some patients disclosed incomplete preservation of phonological lexical access. Poor pseudohomophone–picture matching revealed an inability to access the POL and semantics via GPC. Four of the five patients repeated nonwords and words flawlessly.

Reading errors were less frequent than naming errors. Reading errors differed qualitatively and quantitatively from those observed in naming pictures. Semantic errors were absent during oral reading. Reading errors for regular, irregular, and rule-governed words were most often phonological and derivational. These patients also produced neologisms and word substitutions. Patients substituted other function words or unrelated words for function words. For most patients frequency or length did not affect reading.

Picture naming was poor. Naming errors were primarily semantic. Phonological, derivational, and neologistic errors were infrequent during naming. Patients were more likely to produce unrelated words or not to respond when naming than when reading. Although spontaneous speech contained numerous word-finding errors, phonological errors were nonexistent.

The naming disturbances observed in our patients relate to different sources of impairment. Semantic access and picture naming were both poor for VA, VD, and NS. Picture naming was poorer than semantic access in these patients. The difference between naming and semantic access scores in these three patients suggests that their naming deficits might relate to poor lexical access and degradation of semantics. In contrast, LC and SE had relatively intact semantic access and produced few errors when naming, suggesting that the level of the naming impairment relates more to difficulty accessing the POL from semantics. Therefore, the severity of the nominal deficit may well relate to level of impairment. Degradation to the semantic system may cause a more severe nominal deficit than one related solely to semantic egress deficits. We will discuss LC's performance in depth later (see *Differences between deep and phonological dyslexia*). However, semantic errors were blatantly absent from oral reading. Based on current models, if a patient has a deficit at any one of the stages common to naming and oral reading, errors should be similar across all tasks mediated by these cognitive subsystems. This was not the case in our patients.

Current serial neuropsychological models of oral reading do not explain our results. A serial dual-route model predicts that reading, in the presence of impaired GPC, occurs through the indirect lexical semantic route. A serial dual-route model would predict that patients with accompanying semantic deficits, as was the case with VA, VD, and NS, should produce semantic errors during oral reading. Given this traditional dual-route assumption VA, VD, and NS should be deep dyslexic and their reading errors should be qualitatively and quantitatively similar to picture naming errors. However, none of these patients made semantic errors when reading.

Analogy models incorporate an OIL to POL route. This direct route from the OIL to the POL replaces the sublexical GPC route. Reading of both words and nonwords occurs through the POL. The direct OIL to POL route is the primary reading route. In this model phonological dyslexia can arise from impairment to the direct OIL to POL route. Readers read nonwords via the semantic route. Incorrect nonword reading occurs because they have no semantic representations. If the direct route is impaired and reading takes place via semantics analogy theory predicts disproportionate difficulties with function words. Reading via the semantic route cannot account for an inability to read nonwords when presenting with additional semantics deficits. Function words, like nonwords, have minimal semantic representations and therefore are more susceptible to error when read through the semantic system. Our patients did not read function words more poorly than other words.

When the direct OIL to POL route is spared, analogy theorists (Friedman, 1995) argue that phonological dyslexia arises from disturbances to the POL. Poorer nonword reading compared to word reading occurs because of the limited representations for nonwords in the POL. Impairment to the POL does not account for poor nonword reading in our patients. Impairment to the POL should cause similar errors in naming, spontaneous speech, repetition, and reading. This was not the case for our patients. Degradation to the POL would not allow patients to read words they could not name. Both require the same phonological representation. None of our patients demonstrated a general phonological impairment. All our patients had intact phonological representations, evidenced by the absence of phonological errors in repetition and spontaneous speech. Therefore, analogy models would predict that nonword reading should be adequate because phonological representations were intact.

Orpwood and Warrington (1995) argued that current neuropsychological models of language containing a single POL cannot account for the marked dissociation between naming and reading errors. Conflicting with traditional theories, they raised the suggestion that there are two phonological output lexicons. One POL subserves oral reading and the other naming. The notion of two separate output mechanisms accounts for the data but lacks parsimony. The Simultaneous Activation Hypothesis explains the dissociation between naming and reading in the phonological dyslexic reported by Orpwood and Warrington (1995) without postulating two output mechanisms. In the presence of an impaired semantic module additional unambiguous information provided by the direct OIL to POL route is sufficient to constrain activation of the correct phonological entry even when GPC is impaired. This additional information is unavailable during naming, in which deficient semantic information provides the only constraint on phonological selection, resulting in a semantic error.

To account for dissociations between linguistic tasks requiring similar cognitive processes researchers raise the possibility that interactions occur among the different reading routes (Hillis & Caramazza, 1991, Miceli, Capasso, & Caramazza, 1994). Hillis and Caramazza (1991) in their Summation Hypothesis proposed interactions between the semantic route and GPC. This interaction model discounts the existence of the direct OIL to POL route. In this model interaction of an intact GPC mechanism with degraded semantic information at the POL circumvents the production of semantic errors in reading. The Summation Hypothesis encounters problems when semantic errors are absent in oral reading and present in naming but both the semantic system and the GPC route are impaired.

Our results are also counterintuitive to those predicted by the Summation Hypothesis (Hillis & Caramazza, 1991; Miceli et al., 1994). In the Summation Hypothesis, both a lexical route via semantics and a sublexical GPC route are available for reading. A direct OIL to POL route is nonexistent. Information from both the lexical and sublexical routes summate at the POL to activate a phonological representation. In this model, the absence of semantic errors in reading, and their presence in naming occurs only with sparing of GPC. Information from the GPC route feeds forward to the POL effectively blocking the production of semantic errors during reading. Semantic errors occur in reading *only* when damage affects *both* lexical semantics and GPC. All our patients showed impaired GPC with co-occurring deficits to either semantics or from semantics to the POL. In this case the Summation Hypothesis would predict the presence of semantic errors in both reading and naming because additional information is not available through the GPC route to ‘‘*block*’’ the production of semantic errors when reading. Lexical-semantic information computed from the stimulus picture or the written words is the only information available to constrain activation of a phonological entry in the POL. Therefore, errors in reading should mirror those produced in naming and deep dyslexia should result.

The performance of these five phonological dyslexics is consistent with a model of lexical processing in which all reading routes activate simultaneously to constrain phonological selection. We can phrase this failure to produce semantic errors in oral reading more explicitly. These reading routes are not functionally encapsulated in the traditional sense (Fodor, 1983). Rather, these routes all provide relevant information necessary to constrain activation of a correct phonological entry in the POL. Information from all three routes converges at the POL to activate the correct phonological entry.

Differences in errors during oral reading and picture naming. The dissociations between reading and naming in these phonological dyslexics provide further support for the Simultaneous Activation Hypothesis (Southwood & Chatterjee, 1999). Serial cognitive neuropsychological models assume word reading relies on maximal weighting of the semantic route (A) (see Fig. 1). When naming the semantic route is also maximally weighted (*m* in Fig. 1). Therefore, semantic errors in naming and reading should be qualitatively similar and the weighting given to A should equal that given to *m*. The marked discrepancy in semantic errors produced when reading and naming suggests that weightings given to A and *m* are not equivalent and the direct OIL to POL (B) and GPC (C) routes contribute to reading. Weightings given to B and C provide additional information to activate the correct phonological entry above threshold. The fact that the sublexical GPC route is impaired suggests that the weighting given to B is larger than that given to C when these subjects read. Semantic errors are absent in reading because additional information from the spared OIL to POL route facilitates activation of the correct phonological entry, negating suprathreshold activation of a semantic associate.

Semantic errors appear in naming because no additional information constrains activation of the appropriate phonological entry. Deficient semantic information accounts for the occurrence of semantic errors in naming. When naming weightings of routes *n* and *o* in Fig. 1 are minimal or zero. 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.

The Simultaneous Activation Hypothesis provides a plausible explanation for the dissociation between phonological errors in reading and naming. Degraded information from the GPC and the semantic routes arrives at the POL and interacts with accurate or degraded information from the OIL to POL route. In this instance, the ambiguous information from these different routes reduces the likelihood that a complete phonological representation will activate to threshold, increasing the probability of a phonological error during oral reading. The probability of producing a phonological error in other output tasks decreases because ambiguous information provided by the GPC and direct OIL to POL routes does not interact with semantic information received at the POL.

Additional evidence for simultaneous activation of reading routes. A Simultaneous Activation Hypothesis can also account for errors produced when reading nonwords and function words as well as derivational errors. Error patterns from these tasks provides additional evidence that all three reading mechanisms activate simultaneously during oral reading.

Nonword errors. The Simultaneous Activation Hypothesis can account for the frequent substitution of visually/phonologically similar words for nonwords. Maximal weighting to the GPC route occurs when reading nonwords and pseudohomophones. However, the direct OIL to POL (B in Fig. 1) and the semantic (A in Fig. 1) routes, although given less weighting, also activate on detection of a letter string. Information from these sources interacts with GPC information to activate the most suitable response. The direct OIL to POL route activates visually/phonologically similar words (*x*) during nonword reading. This information is sufficient to activate a phonological entry that feeds forward for further processing at the selection and sequencing level. Therefore in the absence of sufficient information from C additional information supplied by A + B yields *x*. Information provided by C may reinforce activation of *x*. Substitution of words for nonwords invites the conclusions that nonwords elicit simultaneous activation of words in the OIL, potentially activating to threshold a phonological entry in the POL. In other circumstances, information provided by B is insufficient to activate a phonological entry in the POL. This information interacts with degraded information from GPC generating random phonemes for output, resulting in a neologism.

Function word errors. Function words have weak semantic representations (Friedman, 1996). Researchers assume that function word reading relies not only on semantic input but input from other sources as well (Morton & Patterson, 1980). This notion is consistent with the Simultaneous Activation Hypothesis. Constraining a phonological entry for a function word relies on information supplied by the direct OIL to POL (B) and GPC (C) routes. Reading function words causes B and C routes to receive stronger weightings than the semantic route (A). That is, A + **B** + **C** yields the appropriate function word. Activation of a function word cannot occur unless both B and C also provide supportive information. In the case of phonological dyslexics, the POL receives degraded information from the GPC route that interacts with information from the direct OIL to POL route and minimal semantic information. The POL therefore, does not receive all the necessary information to support activation of the appropriate function word to threshold. Rather other function words may also be activated and therefore output for further processing at the level of selection and sequencing. This notion may be particularly applicable to function words that contain little semantic information (e.g., auxiliaries). However, the weightings given to the different routes may vary with the function word read. The weighting given to semantic system may be greater for function words carrying more semantic information (e.g., prepositions). Further analysis is required to determine how weightings vary depending on the semantic information carried by the function word.

Derivational errors. Derivational errors have received little attention in the reading literature. These phonological dyslexics produced derivational errors involving inflectional operations (e.g., ‘‘flowers’’ for ‘‘flower’’) when reading aloud. In most instances where an inflectional form occurred a derivational error was produced. GPC information in conjunction with semantic and direct OIL to POL information activates these words. Words that differ in terms of their inflectional endings may require additional GPC information. Therefore, inflectional forms may be more reliant on GPC information to achieve complete activation. That is, information from semantics and the direct OIL to POL may activate phonological entries with different bound morphemes. However, additional information supplied by GPC is also necessary to activate the correct free morpheme to threshold. If the GPC route supplies degraded information, it may be insufficient to activate the correct word resulting in a derivational error. At this point, we can only address derivational errors related to inflectional operations, as none of the patients produced errors on words requiring derivational operations (e.g., pity–pitiful). A decompositional hypothesis (Job & Sartori, 1984) cannot explain entirely the derivational errors produced in oral reading. If the root morpheme and suffixes are stored as separate units, we would expect that all subjects should produce similar numbers of derivational errors in both reading and naming, particularly if the problem is related to phonological lexical access. One of patients produced a number of derivational errors in reading but they were nonexistent in her naming. Further, derivational error frequency should be similar in oral reading and naming.

Differences between deep and phonological dyslexia. Our claim is that phonological dyslexics may have a semantic deficit despite not making semantic errors in reading. This claim raises the question of how semantic errors could ever occur in reading. When semantic errors do occur, as in deep dyslexia, they are less frequent than those that occur in naming. How can the Simultaneous Activation Hypothesis account for deep dyslexia? In order to account for differences between deep and phonological dyslexia we will refer to LC's data. Initially LC presented with deep dyslexia (Southwood & Chatterjee, 1999). GPC was severely degraded and word reading was very poor. Semantic errors were present in both naming and oral reading, but considerably less so in oral reading.

Nonword and word reading had both improved on her second evaluation. Improvements related to some recovery of both the GPC and the direct OIL to POL route. Semantic errors were no longer present in oral reading. She also showed some improvement in her naming ability but it was disproportionately inferior to her reading abilities. LC's data show incomplete recovery of semantics. The Simultaneous Activation Hypothesis accounts for changes in her error patterns over time for both words and nonwords. Initially LC's nonword and word errors were predominantly neologisms followed by phonological errors and word substitutions. On her second evaluation, most errors were phonologic in nature. The reduction in neologisms and the increase in the number of phonological errors suggest that the GPC and direct OIL to POL route recovered sufficiently to assist in constraining phonological selection. This recovery allowed partial activation of the phonological entry resulting in a phonological error. LC also produced visually or phonological similar words for nonwords on her first evaluation. The percentage of these word substitutions increased on her second evaluation, supporting our initial claim that nonword letter strings activate visually similar words in the OIL, which are fed forward to the POL.

The Simultaneous Activation Hypothesis also accounts for the absence of semantic errors, which were initially present. Semantic errors arise when information from GPC and the direct OIL to POL does not support activation of the correct phonological entry. With recovery, some supportive information becomes available from routes **B** and **C**. This complementary information interacts with impoverished semantic information at the POL. The additional information from B and C facilitates activation of the correct phonological entry and obfuscates the semantic deficit. These data show that the presence or the absence of semantic errors and differences in error types in phonological and deep dyslexia relates to the degree of impairment to all of the reading routes.

CONCLUSION

The data from these five phonological dyslexics provides support for the Simultaneous Activation Hypothesis of reading. Current serial and analogy models of oral reading cannot explain parsimoniously differences in the kinds of errors produced in reading and naming. Specifically, the Simultaneous Activation Hypothesis offers a framework within which to account for dissociations in semantic and phonological errors. Semantic errors are absent during oral reading if additional information is available from the other reading routes to facilitate activation of the appropriate phonological entry. During naming only degraded semantic information constrains activation of a semantic associate in the POL rather than the correct phonological entry. The opposite dissociation, the presence of phonological errors in oral reading and their almost nonexistence in picture naming, occurs because additional information from other reading routes is available to activate a partial phonological entry in reading but not in naming. We can explain the large proportion of visually/phonologically similar words produced when reading nonwords and pseudohomophones and the differences in errors when reading function words with our hypothesis. In the case on nonwords and pseudohomophones, activation of the direct OIL to POL route occurs simultaneously with GPC activation. Because additional GPC information is lacking, the POL sends a phonologically similar word to the selection and sequencing level for processing. Information from both the GPC and direct OIL to POL routes primarily activates function words. Again, information from the GPC route is insufficient to assist in constraining the correct phonological entry, resulting in the production of alternative function words. Weighting to the semantic system for function words is minimal, providing little additional information to constrain the correct function word. In conclusions, serial cognitive neuropsychological models do not explain dissociated error types in reading and naming. These dissociations support the notion that multiple routes simultaneously constrain phonological entries in the POL. The weighting of these routes varies with task demands. Further, the difference between phonological dyslexia and deep dyslexia is one of degree.

APPENDIX A: SPONTANEOUS SPEECH SAMPLES

LC

Tell me a little about why you are here? I had an aneurysm. I cannot read, write, or multiply.

Picture description. This looks like today, it's beautiful outside. There's um. . . . They're having a picnic. This couple and he's reading and she's having a soda. The other gentleman over here is flying a kite. . . . out the back yard. Oh. . . . There's also some um . . . sailing going on and some fishing and a little swimming over here. It's a beautiful day.

VA

Tell me a little about why you are here? I had a stroke.

Picture description. A picnic, they having a picnic. That's a kite, boat. That's the beach. That's outside. That's a garage. They outside in the yard.

VD

Tell me a little about why you are here? I am just. . . . with things wrong with me.

Picture description. Fellow in whites flying a kite. Dog watching him. . . . and the wife and the young man is having lunch together.

NS

Tell me a little about why you are here? You see I can't think of one actually.

Picture description. Well there's a big green tree and a green ashland bush. . . . green tree with kite . . . holding lady. . . . Pouring cocoa . . . a cocoa basket.

SE

Tell me a little about why you are here? Well I had to take a lot of tests and everything. . . . And uh. I don't know what dis is down here where they stick me at and everything. I had a cat scan and then they had to stick that thing down my neck and then I had a uh checking with my heart and then that was about it.

Picture description. I see a car. . . . I see someone reading. I see someone pulling juice, it's a picnic basket out there and I see a flag. I see someone flying a kite. . . . I see a dog. . . . It's a sail boat. I see someone getting some water out the sea and I see uh a shovel and a pail and see a radio. I see some flip flops. I see a tree and I see a dock right there.

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