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Phonological dyslexia: a test case for reading models

Elise Caccappolo-van Vliet[1, 2], Michele Miozzo[3], and Yaakov Stern[1, 2, 3]

[1]Cognitive Neuroscience Division, Taub Institute for Research in Alzheimer's Disease and the Aging Brain, [2]Gertrude H. Sergievsky Center, [3]Columbia University

Address for correspondence:
Michele Miozzo
Department of Psychology
Columbia University
1190 Amsterdam Avenue
New York, NY, 10027

Fax: (212) 854-3609
Phone: (212) 854-8605
e-mail: mm1150@columbia.edu

Abstract

Following brain damage, skilled readers may encounter more severe problems in reading nonwords than familiar words, a type of deficit referred to as phonological dyslexia. We report two individuals with Alzheimer's disease who show phonological dyslexia. Although highly accurate in reading familiar words aloud (even those with irregular spelling, e.g., sew), they were quite impaired in nonword reading. Both patients performed well in phonological tasks involving the repetition, identification, and manipulation of phonemes of orally presented words and nonwords. These results challenge the account proposed in the context of connectionist and evolutionary theories that phonological dyslexia originates from a phonological deficit. These results are consistent with reading models like the dual-route model that attribute phonological dyslexia to a deficit that selectively affects the reading mechanisms responsible for deriving the sounds of nonwords. According to these models, such a deficit is not necessarily accompanied by a more general phonological impairment.

The term phonological dyslexia is used by neuropsychologists to describe reading deficits that affect nonwords (nep, cabe) more severely than familiar words. This disturbance appears in adult skilled readers following cortical brain damage; a developmental form has also been reported in children without apparent cortical lesions (e.g., Temple & Marshall, 1983). The understanding of phonological dyslexia has, in addition to obvious clinical consequences, implications for the current debate on reading processing. As we will see below, current models of reading offer different accounts of phonological dyslexia. A better knowledge of this deficit can severely constrain such models and as such it is of primary theoretical significance.

The dual-route model proposes that two types of mechanisms, in part neuroanatomically distinct, support reading aloud (see Coltheart et al., 2001, for a recent instantiation of this account). One series of mechanisms, the lexical route, is implicated in the retrieval of stored information about the orthography, semantics, and phonology of familiar words. An alternate route, the non-lexical route, allows readers to derive the sounds of written words by means of mechanisms that convert letters or letter clusters into their corresponding sounds: the non-lexical route. The non-lexical route is functionally limited in that it does not provide information about word meaning, nor, in a language like English or Italian, does it guarantee the correct pronunciation of a number of words. Nevertheless, the non-lexical route is responsible for deriving the sounds of nonwords; its selective damage would result in phonological dyslexia (Berndt et al., 1996; Coltheart, 1985; Derousné & Beauvois, 1985).

Another class of models, which we refer to as "triangle models," offers a different account of phonological dyslexia. According to these models, reading aloud depends on the joint processing of mechanisms that translate orthography into phonology and mechanisms that bind word meaning and phonology. This type of architecture has been proposed in several connectionist models (e.g., Plaut et al., 1996; Seidenberg & McClelland, 1989). Although differing on a number of details, the various triangle models all share the assumption that identical processes support the reading of words and nonwords. That is, in contrast to what is proposed by the dual-route model, there are no mechanisms specifically involved in the processing of nonwords. Within the framework of triangle models, the cause of phonological dyslexia is assumed to be an impairment in the representation of phonological information (Friedman, 1996; Harm & Seidenberg, 2001; Patterson 2000; Plaut et al., 1996). Various factors conspire to make nonwords more vulnerable to a phonological impairment. Because nonwords depend more on orthography-phonology mapping, have less stable phonological representations, and do not benefit from the collateral support of semantics, conditions that alter the representation of phonological information are expected to have sizable effects on nonword reading. It is further proposed that when the phonological impairment is mild, only nonword reading should be affected, thereby accounting for pure cases of phonological dyslexia in which reading of familiar words is spared (e.g., Beauvois & Derousné, 1979; Funnell, 1983; Shallice & Warrington, 1980). We refer to this explanation of phonological dyslexia as the <u>phonological impairment hypothesis</u>.

Also Farah, Stowe, and Levinson (1996) appealed to the phonological deficit hypothesis, although from different theoretical premises. Essentially their idea is that because reading is, from an evolutionary perspective, a recently acquired function, it cannot depend on specialized brain regions. Consequently, brain damage cannot cause selective reading deficits. However, damage to cognitive functions with dedicated brain regions (e.g., vision or phonology) can affect reading. In particular, phonological deficits should have selective effects on nonword reading, essentially for the reasons explained above: because nonwords require additional phonological processing for word sounds to be assembled.

Proponents of dual-route models do not deny that phonological deficits could affect reading, particularly nonword reading. A point of divergence concerns the role of phonological deficits: whether they should invariably accompany this form of dyslexia, as proposed by the phonological impairment hypothesis, or whether other factors can also yield phonological dyslexia, as proposed by dual-route models. It is striking that patients with acquired phonological dyslexia almost invariably fail in a range of phonological tests, including, for example, nonword repetition and phoneme manipulation tasks (e.g., "repeat the word <u>sharp</u> without the initial phoneme"). This association of deficits lends support to the phonological deficit hypothesis. However, there have also been cases of acquired phonological dyslexics who perform well on phonological tasks. These cases have been reported much more rarely: in fact, only two or three cases showed this type of dissociation. One case is LB (Derousné & Beauvois, 1985), a French-speaking patient who, for example, could assemble nonwords if provided with the individual phonemes (e.g. /g/, /r/, /a/ → /gra/) and could pronounce the last phoneme of a word spoken by the experimenter. The second case, the Italian speaker RR (Bisiacchi, Cipolotti, & Denes, 1989), was able to pronounce the first phoneme of aurally presented words and performed within controls' range in the difficult spoonerizing task, which requires swapping word onsets (as in <u>Niccolò Macchiavelli</u> → "Miccolò Nacchiavelli"). More recently, Caccappolo-van Vliet, Miozzo, and Stern (in press) documented phonological dyslexia in a subject (RG) diagnosed with Alzheimer's disease. Due to a general cognitive decline, RG could perform only phonological tasks that required relatively simple instructions: word and nonword repetition, rhyme judgment ("Do the words <u>pair</u> and <u>bear</u> rhyme?"), production of words that share onset phonemes ("shot" → "sugar") or rhyme ("table" → "cable"). RG performed flawlessly on all these tasks. The dissociations between impaired nonword reading and preserved performance on phonological tasks documented in these patients are problematic for the phonological deficit hypothesis. These dissociations, however, are in line with dual-route models, which do not assume phonological deficits to be the principal cause of phonological dyslexia and thus do not anticipate a recurrent association between phonological deficit and nonword reading impairment.

Upon closer scrutiny, however, these dissociations might appear to be less compelling. Several questions have been raised about these patients' data. For example, Patterson (2000) questioned whether LB represented a convincing case of phonological dyslexia, since accuracy was not far better for words (range 74-94%) than nonwords (range 48-85%). Patterson (2000) raised similar concerns about patient RR, as there were indications that this patient could read short nonwords but had some problems with low frequency abstract familiar words. Harm and Seidenberg (2001) suspected that LB's relatively good performance in the phonological tasks resulted from rehabilitative training that emphasized phonological reading and improved LB's phonological awareness. Regarding patient RG, data were limited to phonological tasks with procedures simple enough to be understandable to the patient. In short, if previous neuropsychological data do not allow one to make conclusive claims about whether phonological dyslexia and phonological deficits dissociate, it also appears clear that this issue needs further investigation. An opportunity to address this issue is offered by the present report of two patients with progressive dementia, MO and IB, who encountered relatively severe problems in reading nonwords. Word reading remained highly accurate in both patients, who also performed remarkably well on a wide variety of phonological tasks. Serious cognitive damage prevented the administration of a few tasks; still, our results provide significant constraints on current accounts of acquired phonological dyslexia.

Case Reports

MO is a 48-year-old, right-handed Caucasian male with a master's degree in business who worked as an accountant. IB is a 77-year-old, right-handed African-American female with 12 years of education who was previously employed as a secretary. Both patients were diagnosed with probable Alzheimer's disease (AD) according to strict neurological criteria based on full clinical evaluation and extensive neuropsychological testing. MO's medical history is significant for autosomal dominant AD in his father, paternal uncle, and three siblings, all of whom were diagnosed in their forties. Medical history for both patients was negative for psychiatric disease, head trauma, alcohol abuse, and other medical diseases, and neither patient demonstrated behavioral or psychiatric symptoms. Neither patient showed developmental dyslexia, according to reports of their family members.

Neuropsychological testing of both patients revealed significant deficits in multiple cognitive domains, including verbal and visual learning and memory, attention, abstract reasoning, and confrontation naming (see Table 1). We analyzed whether oral picture naming responses revealed phonological distortions, i.e., substitutions, additions, or omissions of one or more phonemes. Responses of this type were rarely observed with MO (5/770, 0.6%) and never with IB (0/75). Examples of MO's responses include <u>ruler</u> → "roller," <u>beenie</u> → "beeper." On a modified version of the Mini Mental Status Examination (mMMSE; Mayeux et al., 1981), IB obtained a score of 33/57, which suggests moderate dementia; MO's mMMSE score of 42/57 is indicative of mild dementia. Both also showed impaired nonword reading. This latter deficit spurred the current investigation, which was initiated in February 2002 for MO and May 2002 for IB, and ended in March 2003 for both. The investigation obtained IRB approval. IB's testing was limited because she agreed to be evaluated only when she had a previously scheduled appointment at the university hospital. Neither patient participated in a language rehabilitation program. A comparison of the mMMSE scores of the patients at the beginning and end of our investigation reveals that, during the testing period, cognitive abilities remained stable for IB but declined for MO (his score decreased from 42 to 33). (Note that in order to prevent a systematic effect of cognitive decline, the data for reading and phonological processing were obtained in the same testing sessions.)

Is reading impaired?

The results of the word reading aloud tasks are summarized in Table 2. We used several lists to compare the patients' accuracy in reading words with regular and irregular spellings (e.g. pink vs. pint). They responded accurately (>90% correct) to both types of words ($\chi s^2<1$). The patients were as accurate as unimpaired readers with the lists of irregular words compiled by Glushko (1979) (range: controls' means = 88-92%; MO and IB = 90-100%). Derived, inflected, and compound words were read aloud as accurately ($\chi^2<1$) as monomorphemic words matched for frequency and length. Accuracy did not vary as a function of variables such as concreteness, grammatical class, frequency, or word length. Of particular interest is the finding that neither patient encountered problems with functors (closed class words such as prepositions and determiners). In this respect, MO and IB differed from the group of phonological dyslexics reported by Friedman (1996), who were impaired in reading functors.

We administered two tasks to assess reading comprehension. In the first task, the patients were shown four written words and were instructed to point to the word spoken by the experimenter (e.g., "glass") rather than to a semantic foil (cup), a phonological-orthographic foil (gloss), or an unrelated foil (bloom). The second task had the same design with the exception that the target stimuli were pictures rather than spoken words. The responses of MO and IB were invariably correct in both tasks (12/12 and 20/20, respectively), a result that suggests that reading comprehension was fairly intact in both patients.

By contrast, nonword reading aloud was impaired. The patients were informed that they would be presented with "invented" words. We adopted a lenient scoring procedure:

we considered responses correct if they conformed to rules of English pronunciation (Venezky, 1970) or to pronunciations of parts of real English words with irregular spellings (e.g. heaf read as rhyming with deaf). Despite such lenient criteria, nonword reading accuracy was below 60% on several lists (see Table 3 for summary). The only exception was Berndt et al.'s (1996) list comprising nonwords with high grapheme-to-phoneme correspondence (GPC, e.g., san or teep): accuracy was 84% for MO and 66% for IB. These results can be explained in various ways: e.g., grapheme-to-phoneme rules that are more frequent are also more resistant to damage; alternatively, if nonword pronunciations are derived by analogy to familiar words, correct responses are more probable for nonwords with common GPC. In a group study, Berndt et al. (1996) observed an advantage for high-GPC nonwords only in patients who scored high in word reading. MO's and IB's responses fit this pattern. Nonwords were presented along with familiar words, except for two lists (Word Attack; Friedman et al., 1992). Accuracy, however, did not change as a function of modality of presentation, as is evident from Table 3. Unimpaired readers perform much better with nonwords than these patients did. For example, with Friedman et al.'s list (1992), unimpaired readers scored above 80% (data from Friedman et al., 1992), whereas our patients scored lower than 40%. Two results commonly observed in phonological dyslexia were replicated with our patients. First, lexicalizations – errors consisting of familiar words such as bip → "hip" – accounted for many of the errors committed by MO (21%) and IB (43%). Second, single phoneme errors (substitutions, deletions, and additions) were far more common with vowels than with consonants (MO: 77 vs. 11; IB: 83 vs. 29), a result that reflects the greater variability in the letter-sound correspondence of vowels in English. (Note that nonwords comprise more consonants than vowels.)

We examined the possibility that the nonword reading impairment stemmed from the verbal short-term memory (STM) deficit that also affected our patients. Various authors (e.g., Caramazza, Capasso, & Miceli, 1996; Derousné & Beauvois, 1985) have pointed out that if nonword letter-sound transcoding occurs serially, sounds are probably stored in the STM structure until the assembly of the whole sound sequence is completed. Conditions of reduced STM capacity like those experienced by our patients could give rise to nonword reading problems, and these problems should be particularly pronounced with longer items. However, error rates did not increase from 4-letter to 6-letter nonwords (see Table 3), a finding that does not lend support to the hypothesis that an STM deficit underlies the nonword reading deficit of our patients.

Is phonological processing impaired?

MO and IB were tested with a wide range of tasks that have revealed phonological deficits in past studies. The experimenter aurally presented the items and, depending on the phonological task, the patients repeated a word or nonword, or identified, produced, or manipulated certain phonemes. Instructions, material descriptions, and results are reported in Tables 4 and 5. Because of her limited availability, IB completed a few tasks only partially. Items were counterbalanced for the critical variables and were approximately matched in the tasks partially completed by IB.

Despite our repeated attempts, IB failed to understand the instructions for the spoonerism task, in which proper names were to be repeated with swapped onsets (as in John Kennedy → Kohn Jennedy). This finding is of little surprise given the complexity of the task instructions and the severity of IB's dementia. The nonword triplet repetition task was discontinued with MO because of his frustration with consecutive failures. We are inclined to attribute these failures to MO's severe verbal short-term memory (STM) deficit. When he was assessed with the nonword triplet repetition task, MO's scaled digit span score was 4. Note that IB's scaled score was higher: 6. It is also likely that MO's STM deficit affected his responses on the spoonerism task. In 12/64 (19%) of the trials, MO had problems repeating the final syllables of the second name, as in the responses "Pike Mia" (instead of Pike Miazza, for Mike Piazza) or "Zed Lezzlin" (instead of Zed Leppelin, for Led Zeppelin). Because the spoonerism task involves STM, and because the final syllables are stored longer in STM, these syllables are most likely to be affected by an STM deficit. Importantly, however, MO always produced the first name correctly and did not have difficulty exchanging the word onsets.

Considering their limitations, it is even more remarkable that both patients scored, on average, higher than 95% correct in the various phonological tasks. Moreover, their performance was comparable for words and nonwords (for the individual tasks, $\chi s^2<1$). One could be concerned whether the non-perfect scores obtained in some tasks indicate impairment. To address this concern, control data were gathered for a few of the tasks in which the patients' scores were below 100%. Controls were tested only with nonwords and final phonemes, because we reasoned that these materials were potentially more taxing than words and initial phonemes. For each patient we tested 2 controls matched for sex, age ($\pm$5 years), and education. As can be seen in Table 6, the patients' scores were well within the controls' range. The only exception was IB's score in the syllable counting task, which was slightly below the controls' norms (87% vs. 96%). IB's score is in part accounted for by implausible responses such as "eight" and "nine syllables," which most probably reflect sporadic difficulties in following the task. Overall, the data of MO and IB on the phonological tasks do not indicate impairment. This conclusion is in line with the clinical observation that their speech was not punctuated by the phonological distortions frequently encountered in patients with acquired phonological deficits (Caplan, 1992).

Conclusions

MO and IB, two patients with cognitive decline due to Alzheimer's disease, showed "pure" phonological dyslexia: they encountered severe problems in reading aloud nonwords in the face of a relatively spared ability to read aloud and comprehend familiar words. Results on a number of phonological tests did not reveal a frank phonological impairment, and anomalies in the realization of word phonology were not detected in the patients' speech production. MO and IB provide another example of the dissociation between (impaired) nonword reading and (seemingly spared) phonological processing, a type of dissociation that has only rarely been documented in past studies. Importantly, our cases seem to escape some of the criticisms raised in response to previous studies. Concerns about accuracy of word reading, severity of impaired nonword reading, and effects of remediation programs that emphasize phonological awareness do not apply to our patients: their word reading was extremely accurate across various types of words, their nonword reading was quite impaired, and they had not participated in any language rehabilitation programs. Nevertheless, we were unable to administer a handful of tasks because of the patients' reduced STM and restricted ability to understand and follow complex tasks. With this caveat in mind, phonological deficits were not detected in MO and IB. This conclusion has critical implications for reading models and accounts of phonological dyslexia.

The results of MO and IB can be readily accounted for by reading models that propose distinct mechanisms for familiar words and nonwords. The dual-route model (e.g., Berndt et al., 1996; Coltheart et al., 2001) is one example of a model of this kind. The selective nature of the patients' reading deficits can be explained if it is assumed that brain damage affected only the non-lexical route, leaving the lexical route intact. Such a model also assumes that nonword reading and phonological encoding are supported by (partially) distinct mechanisms. If mechanisms for phonological encoding were spared, it can also be explained why performance in phonological tasks was unimpaired despite poor nonword reading. Dual-route models are also compatible with other features of our patients' data. For example, the tendency to produce words in response to nonword prompts would arise because patients resort to using the intact lexical route. Moreover, if the sublexical route is impaired, patients are expected to respond more accurately to graphemes or graphemic clusters with a limited number of phonological realizations (e.g., typically consonants or low-GPC words) compared to less univocal mappings, as we have observed in MO and IB.

More generally, the data of MO and IB suggest that phonological dyslexia is not a side effect of wide-ranging phonological deficits. Phonological deficits <u>can</u> accompany phonological dyslexia, but this is not <u>necessary</u>. In this respect, the data of MO and IB (and a few other patients) are at odds with the phonological deficit hypothesis, which attributes nonword reading difficulty to a phonological impairment whose impact extends to a variety of tasks, including reading. This hypothesis stemmed from theoretical perspectives as diverse as connectionism and evolutionary theory. Of course, one cannot rule out the existence of a phonological deficit in our patients with absolute certainty. If such a deficit exists, however, it must be very mild given that it was not detected by standard tests. So, at the very least, the question raised by the data of MO and IB is how very mild phonological deficits lead to sizeable nonword impairment. One also has to explain why, in other patients, nonword impairments of comparable severity are associated with sizable phonological deficits. In this respect, the comparison of MO, IB, and three of the patients reported by Berndt et al. (1996) is especially informative.

Although all these patients performed similarly in nonword reading (accuracy range: high-GPC items = 75-85%, low-GPC items = 10-55%), only Berndt et al.'s patients were impaired in phoneme blending, phoneme deletion, and nonword repetition tasks. Ultimately, if there is a way to reconcile the available data with the phonological hypothesis, it is by assuming that different phonological impairments can cause phonological dyslexia. Certain phonological impairments could yield more severe nonword reading deficits than others. Finally, it remains to be explained how phonological deficits leave word reading unimpaired or have less severe effects than for nonwords. This is a critical issue for models that do not incorporate mechanisms specifically involved in nonword reading. The computer simulations of Harm and Seidenberg's (1999) connectionist model remind us that, as the severity of the phonological damage increases, the effects extend to irregular words. How a severe nonword deficit could coexist with spared word reading presents another challenge for models that subscribe to the phonological impairment hypothesis. Computer simulations could be useful for exploring the effects of various types of phonological impairments; naturally, existing implementations of connectionist models (e.g., Harm & Siedenberg, 1999) are promising starting points to investigate this issue.

The specific reading deficits of MO and IB provide another example of how selective cognitive deficits can appear in dementia along with widespread memory and attention decay. The selective nature of such deficits invites the conclusion that, at least in certain brain areas, dementias can be associated with relatively narrow lesions. The lesions of our patients were in areas that are critical for nonword reading. It is significant that phonological dyslexia is almost invariably accompanied by phonological impairment in patients with more extensive brain lesions caused, for example, by strokes. This discrepancy perhaps reflects differences in the brain damage of these two patient groups. Nonword reading and phonology may be processed in contiguous brain regions that both tend to be lesioned by the relatively massive damage caused by strokes. We do not know how frequently relatively 'local' lesions appear in degenerative diseases, but if this is a fairly common event, the investigation of other cases similar to MO and IB will lead to a better understanding of the causes of phonological dyslexia and will provide further data for evaluating reading models.

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Table 1 Neuropsychological Tests: IB and MO

Neuropsychological Tests[a]	Range	Controls[b] Mean (sd)	Patients MO	IB
Modified Mini Mental Status Exam (mMMSE)	0-57	52 (3)		
Winter 2002			42	33
Winter 2003			33	33
Attention				
Cancellation Test (sec)[c]	0-240	63 (27)	120	47
Construction				
Rosen Drawing Test	0-5	3 (1)	3	5
Benton Visual Retention Test: Matching	0-10	9 (1)	9	10
Memory				
Selective Reminding Test:				
(a) Total Recall	0-72	43 (9)	21	22
(b) Delayed Recall	0-12	6 (3)	0	0
(c) Delayed Recognition	0-12	11 (1)	6	3
Benton Visual Retention Test: Recognition	0-10	8 (2)	8	6
Verbal Short-term Memory				
Digit Span (WAIS-R, age-scaled)	1-19	10 (3)	7	6
Language				
Boston Naming Test	0-15	14 (1)	13	8
Controlled Word Association (CFL)	$0\text{-}100^{th}$ ile	64 (31)	22	1
Category Fluency (Animals)	$0\text{-}100^{th}$ ile	36 (28)	3	1
Sentence Repetition (BDAE)	0-8	7 (1)	7	7
Comprehension (BDAE)	0-6	6 (1)	5	5
Abstract Reasoning				
Similarities (WAIS-R, age-scaled)	0-20	10 (3)	7	7
Identities & Oddities (Mattis DRS)	0-16	15 (1)	16	14

[a] Tests were administered in winter 2002, prior to the beginning of the current investigation (with the exception of the re-testing of the mMMSE).
[b] Non-demented elderly (N = 155)
[c] Higher scores (i.e., time in seconds) reflect lower performance.

Table 2 Number of correct responses (%) provided by MO and IB in reading aloud familiar words

Word reading aloud tests	Patient MO		Patient IB	
A. Orthographic Regularity	Regular	Irregular	Regular	Irregular
John Hopkins Dyslexia Battery	35/36 (97%)	34/36 (94%)	34/36 (94%)	34/36 (94%)
Coltheart et al. (1979)	39/40 (97%)	38/39 (97%)	38/40 (95%)	37/39 (95%)
Glushko (1979; Exp. 1)	43/43 (100%)	39/43 (91%)[a]	39/43 (91%)	41/43 (95%)[a]
Glushko (1979; Exp. 3)	41/41 (100%)	41/41 (100%)[a]	40/41 (98%)	40/41 (98%)[a]
Shallice et al. (1983)	37/39 (94%)	72/76 (95%)	38/39 (97%)	71/76 (93%)
B. Word Variables[b]				
a. Concreteness				
Concrete	19/20	(95%)	19/20	(95%)
Abstract	18/20	(90%)	17/20	(85%)
b. Grammatical Class				
Nouns	25/26	(96%)	26/26	(100%)
Verbs	24/26	(92%)	25/26	(96%)
Adjectives	25/26	(96%)	25/26	(96%)
Functors	25/26	(96%)	25/26	(96%)
c. Frequency				
High	25/25	(100%)	25/25	(100%)
Low	25/25	(100%)	25/25	(100%)
d. Word Length				
4 letters	13/13	(100%)	13/13	(100%)
5 letters	13/13	(100%)	13/13	(100%)
6 letters	12/13	(92%)	13/13	(100%)
7 letters	13/13	(100%)	11/13	(85%)
8 letters	13/13	(100%)	13/13	(100%)
C. Word Morphology[c]				
a. Prefixed words	72/75	(96%)	69/75	(92%)
Monomorphemic controls	74/75	(98%)	71/75	(95%)
b. Inflected words	72/75	(96%)	68/75	(96%)
Monomorphemic controls	73/75	(97%)	70/75	(93%)
c. Compounds	71/75	(95%)	71/75	(95%)
Monomorphemic controls	74/75	(98%)	73/75	(97%)

[a] Glushko (1979) reported accuracy data from unimpaired readers (college students); their scores with irregular words (means: Exp. 1 = 87.8%, Exp. 2 = 91.7%) were comparable to those of MO and IB.

[b] Items were from the John Hopkins Dyslexia Battery (Goodman & Caramazza, 1986). In each list, words were controlled for variables affecting reading. For example, concrete and abstract words were matched for frequency, grammatical class, and length.

[c] Items were from Badecker, Hillis, and Caramazza (1990). Morphologically complex words and their monomorphemic controls were matched for frequency and number of letters.

Table 3 Number of correct responses (%) provided by MO and IB in reading aloud nonwords

Test/Word List	Patient MO	Patient IB
Test/Word List	N (%) Plausible Responses	
a. Woodcock-Johnson (Word Attack)	12/28 (43%)	12/28 (43%)
b. Friedman et al. (1992)	27/69 (39%)	18/69 (26%)
c. Glushko (1979)	66/138 (48%)	58/138 (42%)
d. Kay & Patterson (1985)	47/80 (59%)	22/80 (27%)
e. Berndt et al. (1996)[a]		
High grapheme-to-phoneme correspondence	27/32 (84%)	21/32 (66%)
Low grapheme-to-phoneme correspondence	4/20 (20%)	3/20 (15%)
f. Caccappolo-van Vliet et al. (in press)		
4-letters	31/48 (64%)	21/48 (43%)
5-letters	16/48 (33%)	20/48 (41%)
6-letters	27/48 (56%)	30/48 (62%)
Total	74/144 (51%)	71/144 (49%)
Type of error	N (%) Errors	
Lexicalizations (word responses)	53 (21%)	132 (43%)
Single phoneme errors[b]: vowels	77 (30%)	83 (27%)
consonants	11 (4%)	29 (10%)
Complex errors[c]	113 (45%)	42 (14%)
Omissions (failures to respond)	0 (0%)	20 (6%)
Total	254	306

[a] Correct responses to high vs. low grapheme-to-phoneme correspondence nonwords: $\chi^2 = 4.0$ ($p = .04$) for MO; $\chi^2 = 10.7$ ($p = .001$) for IB (Yates' correction applied).

[b] Nonword errors that involved the substitution of a single phoneme (e.g., joon → "zoon"), its deletion (e.g., forch → "orch"), or its addition (e.g., sost → "soist").

[c] In these errors, more than one phoneme was produced incorrectly, as in shan → "charan" or teus → "teususs."

Table 4 Patients' accuracy in phonological tasks involving both words and nonwords

Task	Patient MO		Patient IB[a]	
	Words	Nonwords	Words	Nonwords
Repetition[b] "I'm going to say a word/nonword; repeat it after me"	100% (120/120)	97% (116/120)	98% (93/94)	97% (70/72)
Syllable Counting[b] "I'm going to say a word/nonword; tell me how many syllables it has"	97% (117/120)	96% (115/120)	86% (65/75)	87% (105/120)
Discrimination[c] "I'm going to say two words/nonwords; tell me if they are the same or if they differ by one sound"	100% (60/60)	100% (80/80)	100% (60/60)	100% (80/80)
Phoneme Identification[d] "I'm going to say a word/nonword; does it have a /b/ sound?"	97% (116/120)	95% (114/120)	98% (73/75)	97% (73/75)
Initial Phoneme Production[e] "I'm going to say a word/nonword; tell me its first sound"	100% (50/50)	100% (50/50)	100% (25/25)	100% (25/25)
Final Phoneme Production[e] "I'm going to say a word/nonword; tell me its final sound"	98% (49/50)	100% (50/50)	97% (29/30)	100% (30/30)
Phoneme Blending[f] "I'm going to say the first sound and then the remaining of a word/nonword; blend the two parts together and tell me the entire word/nonword"	100% (25/25)	92% (23/25)	100% (10/10)	90% (9/10)
Phoneme Blending[f] "I'm going to say the first part and then the last sound of a word/nonword; blend the two parts together and tell me the entire word/nonword"	100% (25/25)	96% (24/25)	89% (16/18)	89% (16/18)

[a] In some tasks, IB could be tested only with a subset of the items.

[b] Words (and nonwords) were 1-4 syllables long in the repetition task and in the syllable counting task. Words of different length were shown an equal number of times. In the remaining tasks, items were monosyllabic.

[c] Pairs of CVC words (e.g., jog-fog) and nonwords (e.g., wep-weg) were used. Different pairs accounted for 45/60 of the trials with words and for 60/80 of the trials with nonwords. Pairs differed by one phoneme. The different phonemes appeared approximately an equal number of times in first, second, or third word positions.

[d] The target phonemes were b, k, r, and j and occurred in the initial, middle, and final positions of monosyllabic words and nonwords. One third of the expected responses were no responses.

[e] The target phonemes were consonants.

[e] Different materials were used in the two phoneme blending tests: first phoneme+rest of the word (e.g., l, amp) vs. rest of the word+last phoneme (e.g., was, p). The expected responses were assembled words/nonwords such as l, amp → lamp or was, p → wasp. Some of the items had complex, two-consonant onsets or codas.

Table 5 Patients' accuracy in phonological tasks involving either words or nonwords

Task[a]	Patient MO	Patient IB
Word Rhyme Recognition[b] "I'm going to say two words; tell me whether they rhyme or not"	100% (52/52)	100% (52/52)
Word Rhyme Production "I'm going to say a word; tell me a word that rhymes with it"	100% (65/65)	95% (62/65)
Initial Phoneme Deletion[c] "I'm going to say a word; take away the first sound and tell me what is left"	95% (95/100)	95% (95/100)
Final Phoneme Deletion[c] "I'm going to say a word; take away the final sound and tell me what is left"	97% (97/100)	94% (30/32)
Spoonerism[d] "I'm going to say a person's name; switch the initial letter of the first and the last name and say the resulting name aloud"	98% (125/128)	failed
Three Nonword Repetition[e] "I'm going to say three nonwords; repeat them in the same order"	failed	98% (49/50)
Nonword Completion[f] "I'm going to say a nonword; I'll also show the written form of the nonword with one letter missing. Tell me what letter is needed to complete the written nonword"	98% (49/50)	98% (49/50)

[a] With the exception of the spoonerism task, the materials comprised monosyllabic items.
[b] Rhyming and non-rhyming pairs occurred equally often. The rhymes of rhyming pairs were not spelled identically – port-court is an illustrative example. The rhymes of non-rhyming pairs also shared letters (as in pair-gain). The materials were selected so as to prevent patients from responding on the basis of orthography.
[c] An equal number of expected responses were familiar words e.g. (cart → "art") and nonwords (e.g. sent → *"ent").
[d] An example is Ray Charles → Chay Rarles. There were a total of 64 names, part of which were from Perin (1983), while others were names of American celebrities. We scored whether MO correctly swapped the two phonemes (hence the total N = 128).
[e] Triplets comprised three CVC nonwords (e.g., vin dut bef).
[f] In this task, devised by Derousné and Beauvois (1985), the missing letter occurred in different positions of the monosyllabic words.

Table 6 Percent accuracy in phonological tasks: MO and IB vs. controls

Test[a]	Patient MO	Controls	Patient IB	Controls
Nonword Tasks				
Repetition	97%	96-100%	97%	97-100%
Syllable counting	97%	94-99%	87%	96-97%
Phoneme identification	95%	94-99%	97%	93-94%
Final phoneme production	100%	100%	100%	90-93%
Nonword completion	98%	98-100%	98%	92-96%
Phoneme Blending				
a. onset phoneme+rest of the word	92%	96-100%	90%	88-92%
b. beginning of the word+final phoneme	96%	96-100%	89%	89-96%
Word tasks				
Word rhyme production	100%	100%	95%	88-97%
Final phoneme deletion	97%	97-100%	94%	97%

[a] Task materials and instructions are described in Tables 4 and 5. Each control group was tested with the same materials used for the corresponding patient.