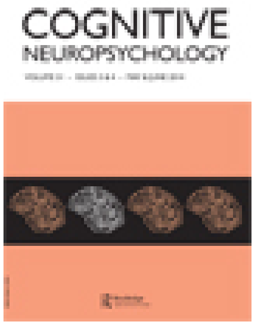

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The Evolution of Deep Dyslexia: Evidence for the Spontaneous Recovery of the Semantic Reading Route

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Most theoretical accounts of deep dyslexia postulate at least two independent deficits which give rise to the observed pattern of reading impairment. One deficit is an inability to derive phonology from orthography sublexically and the second is an impairment in semantically mediated reading. These deficits generate a host of symptoms including an impairment in reading nonwords, a part-of-speech and imageability effect in word reading, and, importantly, the occurrence of semantic paralexias. It is possible, then, that during recovery of deep dyslexia, either one or both of these underlying deficits resolve. We describe a case, RL, with deep dyslexia who showed significant change in his reading performance in the absence of any therapeutic intervention. At 18 months post-onset, unlike at 6 months post-onset, RL no longer produced any purely semantic errors nor did he show effects of imageability or part-of-speech on his oral reading. Despite this change, RL's ability to read nonwords did not improve significantly over this time period. These findings suggest that selective and spontaneous recovery of the semantic reading route can occur independent of significant change in the sublexical reading route.

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INTRODUCTION

Deep dyslexia is one of the many different patterns of impaired reading that can occur after damage to the left hemisphere (Marshall & Newcombe, 1966; 1973; Coltheart, 1980a; Coltheart, Patterson, & Marshall, 1980). The hallmark of this pattern, now well established, is the occurrence of semantic paralexias, i.e. error responses that bear a semantic relationship to the target word. Errors can include superordinate responses (e.g. APPLE → fruit), coordinate responses (e.g. APPLE → pear), subordinate responses (e.g. APPLE → Granny Smith) and syntagmatic or thematically related responses (e.g. APPLE → tart or APPLE → eat) (Coltheart, 1980b). According to Coltheart (1980a), the presence of semantic errors at a rate exceeding chance production (Ellis & Marshall, 1978) almost guarantees the existence of a number of other features including derivational (CRISIS → critical) and visual (THING → thin) errors in reading; an inability to derive phonology from print sublexically; a substantial effect of part-of-speech or grammatical class on reading accuracy (nouns > verbs; content words > functors), and a concreteness or imageability effect with superior reading of concrete words relative to abstract words.

Deep dyslexia has often been interpreted in the context of information-processing accounts of normal reading and there is general agreement that there are probably at least two separate forms of impairment responsible for the range of symptoms listed earlier (Coltheart, 1980a; 1980b; 1982; Marshall & Newcombe, 1973; Nolan & Caramazza, 1982; Shallice & Warrington, 1980). Before offering an interpretation of the deep dyslexia deficits in the context of these models of normal reading, some of the theoretical details must be specified. Although these theoretical accounts have enjoyed considerable popularity over the last decade, there is currently little agreement regarding the functional architecture of the reading system (for further discussion see Besner, Twilley, McCann, & Seergobin, 1990; Coltheart, Curtis, Atkins, & Haller, 1993; Seidenberg & McClelland, 1989). Much of this disagreement revolves around the number of routes available to normal readers for translating print to sound. Most theoretical accounts agree that a lexical semantic reading route is available to normal readers (but see Van Orden, Pennington, & Stone, 1990 for a different perspective). In this route, reading is semantically mediated and phonology is accessed via semantic representations (Coltheart, 1980a; 1980b; 1982; Plaut & Shallice, 1993). Most accounts also agree that readers have available to them a nonlexical or sublexical reading procedure whereby print is converted into sound through general correspondences between letters (or groups of letters) and their phonological counterparts. Whether this conversion takes place through applying abstract grapheme-to-phoneme correspondences or through using larger units of translation still remains an open issue (Friedman, Note 4; Glushko, 1979; Plaut & McClelland, 1993; Shallice & McCarthy, 1985; Sullivan, Note 6). What is important here is that this route is assumed to operate directly from orthography to phonology and is not thought to tap into word-specific representations. The existence of yet a third reading route, which is assumed to contain direct connections between recognised words and their phonological entries and to circumvent the semantic system entirely, is the cause of much controversy. Evidence in favour of this lexical but non-semantic route comes from a patient (WLP) with dementia who was able to read aloud irregular words even though she could not comprehend them (Schwartz, Saffran, & Marin, 1979; see also Coltheart et al., 1983; Coslett, 1991, for evidence from other patients). Because WLP could read irregular words, she must have had access to word-specific knowledge. But this word-specific knowledge is not accessed via semantics since she could not comprehend these items. These findings suggest that an alternative route, which contains lexical knowledge but is not accessed via semantics, must be available to WLP and, by inference, to normal readers. Despite this evidence, there have been several strong proposals suggesting a functional architecture that does not include this third route (Seidenberg & McClelland, 1989).

For the purposes of this paper, we remain neutral on the issue of the number of reading routes. What is relevant for the current study is that there are at least two reading routes, one of which is used to process print sublexically and can be used for nonword reading and a second that is used to process words in a lexical fashion. The two loci of the functional impairments in deep dyslexia are assumed to arise in these two routes. The deficit in nonword reading observed in deep dyslexia is attributed to an impairment to the sublexical reading procedure such that phonological processing of orthography is disrupted. An impairment of the lexical semantic route is also implicated in deep dyslexia primarily because of the high occurrence of semantic errors. According to some views, this semantic route impairment also gives rise to some other symptoms of deep dyslexia, producing a debilitating effect on reading words which have less dense connections. Thus, items such as abstract words, which have fewer predicates or semantic features (Jones, 1985; Plaut & Shallice, 1991; 1992), and verbs and functors, which have fewer semantic associates (Beeman, Friedman, Kwabenah, & Grafman, Note 1) are disproportionately affected by damage to this route. The presence of semantic paralexias, the concreteness effect, and the part-of-speech effect, therefore, all stem from damage to the semantically mediated reading route. It has been argued that the third route or the direct lexical connection from orthography to output phonology is also severed in deep dyslexia with the result that all reading is mediated by the semantic system (Morton & Patterson, 1980).

The question to be addressed in this paper concerns the pattern of recovery of reading in a patient with deep dyslexia. The most striking feature observed in patients with deep dyslexia who have been studied over time is the gradual reduction or elimination of semantic errors. For example, Glosser and Friedman (1990) report the cases of GR and DV, both of whom produced over 10% semantic errors when tested initially. On subsequent testing, neither patient produced any semantic errors. Similarly, SP (Bachy-Langedock & de Partz, 1989; de Partz, 1986) produced 17% semantic errors initially but only 3% semantic errors at a later time. Finally, Laine, Niemi, and Marttila (1990) describe the case of a young woman who produced 7% semantic errors at 5–6 months post-onset, but no semantic errors at 4 years post-onset. Despite these numerous reports, not much attention has been paid to the mechanism underlying this change in reading behaviour over time. Given that deep dyslexia is considered to arise from two separate impairments, it is conceivable that when the deficit resolves, the improvement may be attributable to a change in one or the other reading route selectively or it may arise from a change in both routes simultaneously.

One possible explanation for the recovery of deep dyslexia and the elimination of semantic errors is that it is the impairment in the lexical semantic route that improves or stabilises. An alternative explanation is that it is the sublexical or phonological route that improves. In this latter case, the acquisition of some phonological knowledge may help to constrain or edit out the semantic errors (Coltheart, 1980b; Newcombe & Marshall, 1980). There are now several documented cases of recovered deep dyslexic patients who seem to have acquired some phonological knowledge. For example, at 3 months post-onset, DV (Glosser & Friedman, 1990) made 10% semantic errors and read no nonwords correctly, whereas at 3½ years post-onset he produced only 2% semantic errors and read 14% of nonwords correctly. Similarly, Leonardo (Sartori, Barry, & Job, 1984) made no semantic errors on follow-up and improved from 0% to more than 10% correct nonword reading. Interestingly, both patients still showed effects of grammatical class and imageability on their word reading even though the semantic errors had disappeared. The improvement in nonword reading, albeit slight, suggests that even minimal phonological information about the pronunciation of a word might suffice to block semantic errors. A similar interpretation has been offered for LR's performance (Berndt & Mitchum, in press; Mitchum & Berndt, 1991). Although LR did not show a significant change in nonword reading, Mitchum and Berndt (1991) argued that she had acquired some phonological knowledge since she had learned the correct sound of single-letter graphemes and was able to segment the initial phoneme from the target items. The effect of phonology on her reading was also evident from the types of errors she made. Whereas many of her initial error responses were semantic and unconstrained by letter sounds (e.g. MIND → "think"), at later testing, only 5% of her errors were semantic and the effect of phonological processing was apparent (e.g. EFFORT → "ford"). These findings led the authors (1991, p. 127) to conclude that "phonological processes were now operating to constrain LR's reading responses."

Along with the acquisition of phonology, some patients with deep dyslexia who produce no semantic paralexias on longitudinal follow-up testing seem to show *concurrent improvement in semantically mediated reading.* SP (Bachy-Langedock & de Partz, 1989; de Partz, 1986), for example, improved substantially in her nonword reading, suggesting the re-acquisition of some sublexical phonological processing. Unlike the cases cited earlier, however, no imageability effect was apparent on retest and she showed improvement in the reading of irregular words. A similar pattern was observed in two other cases: GR (Glosser & Friedman, 1990) and a young female studied by Laine et al. (1990) improved considerably in nonword reading from around 5% at time 1 to over 60% correct nonword reading at later testing, suggesting major improvement in sublexical processing. In addition, both also seemed to show a change in semantically mediated reading since neither showed the concrete/abstract superiority nor the grammatical class effect on oral reading at follow-up.

To sum up these findings, all the patients demonstrated some recovery of sublexical processing either with or without simultaneous recovery in lexical semantic reading. The finding of improved sublexical knowledge, however, is not altogether surprising since many of the patients had received some form of intervention, usually directed at remediating the sublexical processing deficit. Because of this external intervention, it is difficult to evaluate the mechanism responsible for the change in deep dyslexia. In order to understand more about the natural and spontaneous evolution of the reading recovery, therefore, information from patients who have not received formal intervention is critical.

In this paper, we present evidence from a deep dyslexic patient who showed a longitudinal pattern consistent with recovery of semantic reading independent of significant change in sublexical processing. At 18 months post-onset, in the absence of any formal intervention, RL produced no purely semantic errors, and word imageability and part-of-speech no longer affected his reading performance. Of particular interest is the fact that RL did manage to read a few more nonwords correctly at follow-up than at initial testing but that this difference was not statistically significant. These results demonstrate one possible form of spontaneous evolution of deep dyslexia, in which the deficit in the semantic reading route may resolve independently of significant change in the ability to perform sublexical orthography-to-phonology conversion.

CASE HISTORY

RL, a 27-year-old English-speaking man, was admitted to hospital in January 1988 following a motor vehicle accident. Prior to the accident, he was an electronics engineer lecturing at a technical college. Initially, after the accident, RL was stuporose, had equal and reacting pupils and a Glasgow Coma Scale of 7/15 (severe range is below 8; Levin, Benton, & Grossman, 1982). Neurological examination revealed an extensive left parietal bone fracture, bilateral soft tissue swelling, and a frontoparietal haemorrhagic contusion on the left. RL was on a ventilator for 25 days and gradually regained consciousness. At 39 days after the accident, he started speaking. His comprehension was considered to be relatively intact and repetition was better than spontaneous speech. His speech output was characterised by a paucity of function words, literal paraphasias, perseverative errors, and neologisms. He was diagnosed as having Gerstmann's syndrome, associated with damage to the parietal lobe of the dominant hemisphere and consisting of left–right disturbance, acalculia, finger agnosia, and alexia. RL also had a dense right hemiplegia. The New Adult Reading Battery was administered at this time and the IQ estimate obtained from it was: verbal IQ 99.6, performance IQ 103.2, and an average full scale IQ 101.4. Arguably the NART is not the ideal tool for testing RL's verbal IQ and may underestimate his premorbid verbal ability. Note, however, that on the NART, RL produced semantic errors such as DEPOT → "milk" (place from which milk is delivered) and HEADACHE → "hair."

Two periods of testing were undertaken: approximately 6 months post-onset (Time 1: June to July 1988) and approximately 18 months post-onset (Time 2: April to August 1989). RL received speech therapy, occupational therapy, and physiotherapy prior to the time at which the present study was started (Time 1) but not thereafter. During the course of our investigations, he was enrolled in a class to learn basic computer skills and received no treatment directed specifically at reading or writing. RL was highly motivated and enthusiastic during the period of testing. The investigations we conducted are presented next. We first characterise the nature of RL's reading deficit and show that his pattern is consistent with that of deep dyslexia. We then go on to present the longitudinal data in which his reading recovery is documented.

PRELIMINARY TESTING

Lexical Decision

Prior to examining RL's oral reading ability, we looked at his ability to classify words on the basis of their lexical status. Previous research on lexical decision tasks with deep dyslexic patients have shown that these patients generally have little difficulty in judging whether letter strings are real words or not (Coltheart, 1980a; Nickels, 1992; Patterson, 1979). This finding has been interpreted as indicating that these patients have retained their knowledge of English orthography. To establish whether this was the case for RL as well, a lexical decision task was administered.

Materials. A list of 64 letter strings (Klein, Note 5) was used. Half of the items were real words and half pronounceable nonwords, matched to each real word. Each item was presented on a single card in bold black print and RL was required to sort the pile of randomly presented items into whether they were words or nonwords. Unlimited time was allowed for completion of this task.

Results. RL classified 58/64 (91%) items correctly, with an equal number of hits (29/32) and correct rejections (29/32). The false alarm items were "shicket," "jine," and "gowl" and the missed items were "abscess," "idea," and "fjord." These results reflect performance significantly above chance ($\chi^2_1 = 25.3$, $P < 0.0001$) and suggest that RL, like many other patients with deep dyslexia, has well-preserved knowledge of the orthographic structure of English.

Semantic Processing

In recent years, three different types of deep dyslexia have been identified. These various forms—input, central, or output type of deep dyslexia—correspond respectively to whether the primary deficit is in imprecise access to semantics, in the semantic system itself, or in the contact between semantics and the phonological output system (Shallice & Warrington, 1980; Shallice, 1988). If the deficit arises in the input from the visual modality to semantics, then one would expect to see semantic errors only on tasks using visual input. If, however, the deficit arises centrally in the semantic system itself, then one might expect to see semantic errors in performance irrespective of the modality of input. Finally, if the deficit arises in the output from semantics, then semantic errors would be observed only on tasks in which output is necessary and not on tasks which do not require output phonology. To examine the integrity of RL's semantic processing and the locus of the deep dyslexia deficit, two tests of semantic comprehension (synonym judgement and semantic judgement) were conducted in both the visual and auditory modalities. Since neither of these tests require a verbal response, they provide a test of RL's ability to access semantics as well as the ability to access meaning within the semantic system itself.

Synonym Judgement

Materials. A list of 76 pairs of words was used (Coltheart, Note 2). On half the trials, the pairs contained synonymous words (e.g. marriage wedding) whereas on the remaining half, the words were non-synonymous (e.g. marriage lantern). Half the pairs contained high-imagery items whereas the second half contained low-imagery items. On one occasion, the pairs were presented in written form (two words on a card) and on a second occasion, the two items were presented auditorily, RL was required to indicate, through sorting into "yes" or "no" piles on the visual task and through pointing to a "yes" or "no" card on the auditory task, whether the items were synonymous or not. The same task (only in the visual modality) was given to 10 normal control subjects (7 female) with a mean age of 26.9 and a mean education level of 17 years.

Results. The normal subjects obtained a mean score of 70.8/76 (93%) correct on the visual version of this task, with no significant difference between high (35.7/38) and low (35.1/38) imagery pairs ($F[1, 9] = 1.0$, $P > 0.10$). On the written or visual version, RL scored significantly above chance ($\chi^2_1 = 35.3$, $P < 0.001$) with 71/76 correct decisions. These results indicate that RL performed as well as the normal subjects on overall score and, like the control subjects, he showed no difference between high- and low-imagery pairs (37/38 high- and 34/38 low-imagery pairs; Fisher exact test = 1.93, $P = 0.18$). RL's performance on the auditory version was identical to the visual version with 71/76 correct pairs and, as on the visual version, there was no significant effect of imagery on performance (37/38 high- and 34/38 low-imagery pairs). To examine the integrity of the semantic system further, another test of semantic judgement was administered.

Semantic Judgement

Materials. RL was given 26 trios of words (Funnell, 1983) in which one word was designated as the target and the remaining two as the choices. Half the trios contained items in which broad semantic distinctions were tested, for example "bough—cake/branch" or "toast—nail/bread" whereas the other half tested more precise semantic distinctions, for example "bough—twig/branch." On one occasion, the trios were presented in written form with the target printed above the distractors and, on a second occasion, the target and the two choices were presented auditorily. RL was required to indicate (through verbal response, pointing, or gesturing) which of the two distractor items was closer in meaning to the target. Normal performance is perfect on this task (Funnell, 1983).

Results. RL's performance on the visual version of the task (23/26 correct) is no different from that reported for normal subjects (Yates correction $\chi^2_1 = 1.4$, $P = 0.02$). All the errors were on trials which required more precise semantic distinctions; he selected "twig" for BOUGH rather than "branch," "lane" for MOTORWAY rather than "road," and "plate" for BASIN rather than "bowl." He scored 24/26 correct on the auditory version, with the two errors again coming from the closely related items; he selected "ship" for CANOE rather than "boat" and "twig" for BOUGH rather than "branch." The two results of interest here are, firstly, that RL's performance (on the visual version at least) is not significantly different from that reported for normal subjects and, secondly, that RL performs equally well on the tasks in the auditory and visual modality.

Summary of Semantic Tests

The results from the two semantic tests are relatively straightforward. When the tasks are presented in the visual modality, RL performs as well as the normal subjects do both in overall score and in the ability to make judgements with high- and low-imagery pairs. When the same tasks are presented in the auditory modality, RL performs as well as he does in the visual modality. These data suggest that RL does not have a deficit in input to semantics nor in the semantic system itself. Instead, they are consistent with the pattern of an output deep dyslexic deficit in which errors arise at a post-semantic locus in the access to phonology.

EXPERIMENTAL TESTING

The first section of the experimental testing characterises the nature of RL's deficit at Time 1. This section is divided into two main parts. In the first part, we establish that RL has an impairment in sublexical processing or accessing phonology directly from orthographic input. We then go on to show that he also has a deficit in accessing phonology via semantics. Finally, we present an analysis of his error responses across a range of tests. The second part of the experimental testing documents RL's performance at Time 2 and at this point, the recovery in his reading is examined and evaluated.

The procedure was identical for most of the experiments. Letter strings were presented individually in lower-case print on white cards. The letters were 6mm high and 1mm thick, generated in bold font using Harvard Graphics. RL was given as much time as necessary to produce an oral response, which was then transcribed for later analysis. Accuracy was measured on all experiments.

The scoring procedure adopted was conservative and may underestimate the full extent of RL's deficit. When RL produced multiple responses, one of which was correct, the item was scored as correct. These multi-item responses often included semantically related forms (e.g. COME → "go behind, come") as well as visually related responses (e.g. SCARCE → "scared, no, scarce"). Since some of the first responses are semantic errors and these trials are considered correct, the final number of semantic paralexias is somewhat underestimated. Like GR (Barry & Richardson, 1988), who also produced the correct word without knowing that he had done so, RL often did not seem aware that he had produced the correct response in the sequence of multiple responses.

I. FIRST TESTING PERIOD: TIME 1

Oral Reading of Nonwords

Nonword Reading

Materials. Sixty-four letter strings (Klein, Note 5), half of which were words and half nonwords derived from the same words by changing a single letter (for example "deceit" → leceit and "street" → skreet), were given to RL for oral reading.

Results. RL read 21/32 (66%) words correctly but only 1/32 (3%) nonwords, showing a significant difference between the 2 string types (words versus nonwords: Fisher exact: 27.7, $P < 0.0001$) and confirming his impairment in sublexical letter-to-sound processing. During this task, he attempted to spell out the letters, placing his finger under each one successively, but accuracy still remained low. RL's error responses to nonwords include visually related items e.g. TALUTE → "salute" and TIST → "twist" but also unrelated errors such as RISTORY → "machine" (see Appendix 1A). Interestingly, RL produced some semantic errors to nonwords, for example, NOMEN → "no female."

Homophone Effects: Pseudohomophone Reading

It is clear from the previous experiment that RL is impaired in using assembled phonology for translating print into sound sublexically. It has been argued, however, that some nonword phonological reading may be mediated or assisted by lexical knowledge since normal subjects name pseudohomophone nonwords (PSH), which are homophones with real English words but are not orthographically real words (e.g. TRAX) more quickly than matched nonpseudohomophones (NPSH) (e.g. PRAX) (McCann & Besner, 1987). Furthermore, normal readers can easily make decisions on PSHs such as "does *phocks* sound like a type of animal" (Coltheart, 1980c), suggesting that phonological reading may interact with lexical processing. The next task examined whether RL had any preserved ability to read nonwords that shared phonology with English words.

Material. A list of 40 nonwords, all of which were orthographically legal, was compiled (Klein, Note 5). Half of the items were PSHs (e.g. BRANE) and half NPSHs (e.g. FRANE). The items were randomised and presented in a single block for oral reading.

Results. RL completed only 21 of the 40 items—the test was terminated as he found it too frustrating (see Appendix 1B). Of the 21 items, only 1 (STREAT, a PSH) was read correctly. RL's poor performance on this nonword reading task is consistent with an impairment in sublexical processing. Furthermore, the absence of a difference between PSH and NPSH reading suggests that he does not have access to sublexical phonology via either lexical or nonlexical mediation.

Summary of Sublexical Processing

The results thus far confirm that RL, like other deep dyslexic readers, is unable to use phonological information in translating orthographic input from spelling to the corresponding sounds. These findings are consistent with the view that RL has an impairment in the sublexical route whereby orthography is translated into phonology and this result confirms one of the two loci of damage postulated to be responsible for deep dyslexia.

Oral Reading of Words

In this next section, we report the nature of the deficit in the semantic reading route. Appendix 2 contains the error corpus for all the following oral word reading tasks. RL makes a high proportion of semantic errors, as reported later; the accuracy data are described before the error data.

Effect of Imageability on Oral Reading

A cardinal feature of deep dyslexia is the relative preservation of the reading of high-imageability or concrete words (e.g. ACCORDION, TREE) compared with low-imageability or abstract words (e.g. DEMOCRACY, IDEA). Although this concreteness effect is a well-accepted symptom of deep dyslexia, there are various theoretical interpretations of its underlying mechanism. One view is that there is a difference in the nature of the representation for the two word types, with concrete words being spared since they have more predicates than abstract words (Plaut & Shallice, 1991, 1993; Jones, 1985). An alternative view is that the concreteness effect emerges because the right hemisphere, which gives rise to the deep dyslexia, is capable of processing only concrete but not abstract words (Coltheart, 1980d; Saffran, Bogyo, Schwartz, & Marin, 1980). Whatever the interpretation, it is important to establish that RL shows the concreteness effect as this is a crucial feature of deep dyslexia.

Materials. Fifty-six words, half low-imageability and half high-imageability, taken from Coltheart (Note 2) were given to RL for oral reading.

Results. RL showed the expected discrepancy between concrete and abstract words, reading correctly 27/28 (96%) and 19/28 (68%) high- and low-imageability words respectively (Fisher exact test $P < 0.01$). These results confirm the well-established imageability effect in deep dyslexia (Barry & Richardson, 1988).

Effect of Part-of-speech on Oral Reading

An effect of part-of-speech on reading performance is also one of the hallmark features of deep dyslexia (Coltheart, 1980a). The syntactic hierarchy evidenced in reading performance usually takes the following order: nouns are read most successfully, followed by adjectives and then by verbs. Function words are read most poorly, followed only by nonwords (Barry & Richardson, 1988; Coltheart, 1980a; Friedman, Note 4; Glosser & Friedman, 1990; Patterson, 1979). Two experiments were conducted to assess whether RL shows a part-of-speech effect in his reading: the first compared RL's reading of nouns and verbs and the second compared his reading of content and function words.

Nouns Versus Verbs

Materials. RL was presented with a list of 60 4- or 5-letter words, half of which were nouns and half verbs matched for frequency. His accuracy in oral reading was measured.

Results. A significant effect of part-of-speech on oral reading was observed with RL reading correctly 29/30 (97%) nouns but only 24/30 (80%) verbs (Fisher exact test $P = 0.05$).

Content Versus Function Words

Materials. A list of 50 words, half of which were content and half function words, matched for length and frequency, as given to RL for oral reading.

Results. The significant effect of the syntactic hierarchy on RL's reading was further confirmed with a marked discrepancy between content words (21/25 correct; 84%) and function words (8/25; 32%) (Fisher exact test $P < 0.001$).

Effect of Regularity on Oral Reading

A regularity effect—superior reading of regular compared with irregular words—is not usually observed in patients with deep dyslexia (Patterson, 1979) but is seen in other forms of dyslexia. The prediction, therefore, is that RL will not show a significant difference between regular and irregular words, both of which can be read via the semantic reading route.

Materials. Seventy-eight words (Coltheart, Note 2), half of which obeyed regular spelling-sound correspondences and half of which were exception words, were given to RL for oral reading.

Results. As predicted, there was no significant difference between regular and irregular words in RL's oral reading, with 28/39 (72%) regular words and 33/39 (85%) irregular words correct (Fisher exact test $P > 0.10$).

Effect of Frequency on Oral Reading

Although effects of word frequency are not always seen in the reading performance of patients with deep dyslexia, it has sometimes been suggested that low-frequency words rely on phonological recoding to a greater degree than high-frequency words (Shallice & Warrington, 1975; Seidenberg, 1985). Because phonological recoding is markedly impaired in deep dyslexic patients, it may then be possible to observe an effect of frequency on their reading performance.

Materials. Forty-eight items, half of which were high and half low frequency, matched for regularity, length, and bigram frequency (Seidenberg, 1985), were given to RL for oral reading. The mean frequency of the high and the low items was 11.6 (sd 18.4) and 288 (sd 442) respectively (Francis & Kuçera, 1982).

Results. There was no significant effect of frequency on RL's reading, with 15/24 (63%) high-frequency and 9/24 (38%) low-frequency items read correctly (Fisher exact test $P > 0.05$).

Summary of RL's Oral Reading Performance

The results of the oral reading experiments confirm that RL displays the characteristic features typically associated with deep dyslexia. RL demonstrates significantly poorer reading of abstract than concrete words as well as a significant part-of-speech effect (nouns read better than verbs and content words read better than function words). Although the imageability and part-of-speech of words affect performance significantly, neither word frequency nor regularity have a significant influence on his reading. This pattern is characteristic of deep dyslexia. Up to this point, we have demonstrated that RL's reading shows the expected pattern associated with deep dyslexia. We have not, however, demonstrated the feature that is uniquely associated with deep dyslexia—the presence of semantic errors. In the next section, we provide the analysis of RL's reading errors across the range of tasks reported earlier.

Error Classification

The error responses made by RL, collected across all the word reading experiments (56 high/low imageability, 60 nouns/verbs, 50 content/function, 78 regular/irregular, 48 high/low frequency) are presented in Appendix 2. Errors made to the words on the word/nonword list (Appendix 1A) are also included in this analysis. RL made a total of 131/324 errors but on 41 trials, he self-corrected, leaving a total of 90/324 (28%) errors. The errors are classified as follows: visual errors (V) are those responses that share more than 50% of letters in common with the target without a semantic or morphological relationship, derivational errors (D) are substitutions, omissions, or additions of bound syntactic morphemes; semantic errors (S) are semantically related to the target; mixed errors (M) are combinations of error types (e.g. M—V/S refers to a mixed error that is a combination of a visual and semantic error). Trials on which RL made no response are designated (NR), and errors which are not classifiable are labelled as other (O). The distribution of the errors according to type is shown in Table 1.

As is evident from Table 1, RL produces errors of various types as is often observed in the reading of patients with deep dyslexia. Most important is the fact that 24% of the errors are semantic paralexias, exceeding the usually cited chance level of about 8% (Ellis & Marshall, 1978). This figure somewhat underestimates the semantic error rate as

TABLE 1
Number and Percentage of RL's Errors in Oral Reading

Error Type	*Number*	*Percentage of Errors*
Semantic	22	24
Visual	34	38
Derivational	8	9
Mixed	5	6
Other	21	23

RL also produced semantic errors, which he then self-corrected. These self-corrections are not included in the earlier analysis. However, of the 41 trials on which RL did correct himself, 21 contained a semantic error, for example, MASS → "weight, mass" or PROVE → "theory, prove." If we include these trials in the error analysis, the percentage of semantic errors goes up to 33% (43/131). In comparison with other deep dyslexic patients, the proportion of semantic errors made by RL places him approximately in the middle range of severity. Some cases produce a high proportion of semantic errors such as KE (Hillis, Rapp, Romani, & Caramazza, 1990) and HW (Caramazza & Hillis, 1990), who produce 81% and 51% respectively. Other patients, however, produce a smaller number of semantic errors, which still exceeds chance level—for example, GR (Glosser & Friedman, 1990) and VJ (Laine & Niemi, 1990) produce 11% and 8.6% respectively. The presence of semantic paralexias in RL's reading confirms the diagnosis of deep dyslexia since the occurrence of semantic errors is the unique and defining feature of this phenomenon.

Discussion of RL's Reading at Time 1

Thus far, we have shown that, at Time 1, RL's reading pattern is typical of that associated with deep dyslexia. He is severely impaired in the use of nonlexical phonological reading processes as shown by his inability to read nonwords (including homophonic nonwords). RL's overall reading accuracy for words is 72% but his performance is significantly affected by a number of dimensions, which are characteristic of reading that is semantically mediated. His reading behaviour is influenced by the part of speech and by the imageability of the stimulus but it is not affected by regularity nor by frequency of occurrence of an item. Importantly, RL displays a substantial proportion of semantic errors, the hallmark feature of deep dyslexia. Taken together, these findings are consistent with the diagnosis of deep dyslexia.

II. SECOND TESTING PERIOD: TIME 2

Having characterised the nature of RL's deficit at initial testing, the following section documents the results of follow-up testing conducted 12 months later (18 months post-onset). At Time 2, several of the same tests used at Time 1 were re-administered. For each test, we report the results from Time 2 and then compare them with the results from Time 1. As at Time 1, RL's nonword reading ability is reported first. Thereafter, the variables associated with reading via semantics are assessed and, finally, the error analysis is presented.

Oral Reading of Nonwords

Nonword Reading

The lists of words and matched nonwords at Time 1 were re-administered.

Results. RL read correctly 28/32 (88%) words and 5/32 (16%) nonwords at Time 2, reflecting a significant difference in his ability to read words compared with nonwords (Fisher exact test $P < 0.0001$). Most errors at Time 2 are substitutions of visually similar real words, e.g. DOARD → board, BOPE → hope (see Appendix 1A). A comparison of RL's performance on this word and nonword reading task at Time 1 and Time 2 is shown in Fig. 1.

As is evident from Fig. 1, RL's word reading at Time 2 (28/32) was significantly better than that at Time 1 (21/32) (McNemar $\chi^2_1 = 5.4$, $P < 0.02$). More importantly, his nonword reading showed no significant difference over time with 1/32 correct at Time 1 and 5/32 correct at Time 2 (McNemar $\chi^2_1 = 2.7$, $P > 0.10$). The lack of improvement in nonword

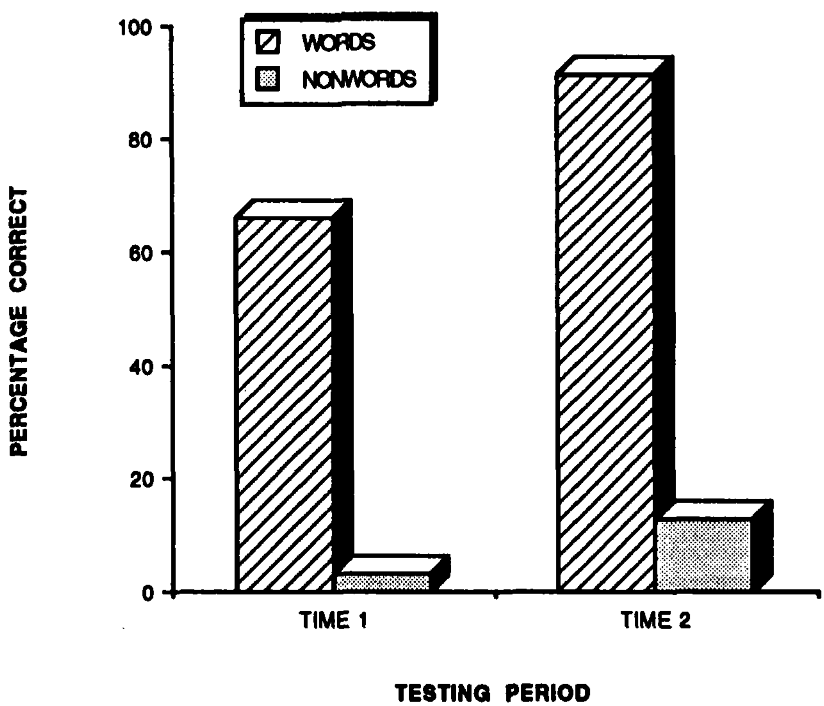

FIG. 1 Percentage correct word and nonword reading by RL at Time 1 and at Time 2.

reading suggests that, over the 12-month period between Time 1 and Time 2, RL had not re-acquired the ability to use general correspondences to translate between printed letters and their sounds. Given the absence of significant change in nonword reading on this task, we examined RL's ability to read the pseudohomophone list administered at Time 1.

Homophone Effects: Pseudohomophone Reading

The list of PSH and NPSH items was re-administered to RL. This time RL managed to complete the entire task.

Results. RL read 8/20 (40%) PSH and 2/20 (10%) NPSH correctly at Time 2, showing a significant advantage for PSH over NPSH (Fisher exact test $P < 0.05$; see Appendix 1B for data). A comparison of the 21 items read both at Time 1 (1/21) and at Time 2 (4/21) suggests that although a few more items were read correctly at Time 2 than at Time 1, there was no significant overall change in RL's ability to read these nonwords across the time interval (McNemar test $\chi^2_1 = 1.8$, $P > 0.10$).

Summary of Nonword Reading

The discrepancy between RL's ability to read words and nonwords observed at Time 1 was still evident at Time 2. Considering the words alone, a significant improvement in RL's ability to read words was observed from Time 1 to Time 2. The same did not hold for the nonwords. Although RL was able to read slightly more nonwords at Time 2 than at Time 1 in both the word/nonword and the pseudohomophone task, the change in performance across time was not statistically significant. The absence of significant change in nonword reading suggests that RL's ability to translate orthography directly into phonology did not change substantially over the 12-month period. Of note is the significant difference in his ability to read PSH relative to NPSH at Time 2, possibly reflecting the improvement in his word reading ability.

Oral Reading of Words

Effect of Regularity on Oral Reading

The same 78 words (39 regular and 39 matched irregular words) were re-presented to RL. RL read correctly 37/39 (95%) and 36/39 (92%) regular and irregular words respectively. As at Time 1, there was no significant difference between regular and irregular words (Fisher exact test $P > 0.05$).

Effect of Part-of-speech on Oral Reading

The same list of content and function words administered at Time 1 was re-presented to RL. He read correctly 25/25 content and 24/25 function words, showing no significant effect of part-of-speech at Time 2 (Fisher exact test = 1.02, $P > 0.05$). The single error HERE → "there," a function word substitution, is classifiable as a mixed visual and semantic error. Figure 2 shows the change in reading across the two testing periods.

Using a log linear model, the interaction between word type (content/function) and time (Time 1/Time 2) approaches significance ($\chi^2_1 = 3.5$, $P = 0.06$), suggesting that the difference in performance across time was probably attributable to the disproportionate recovery at Time 2 of function word reading relative to content word reading.

Effect of Concreteness on Oral Reading

Although no formal testing was conducted to assess RL's reading of concrete versus abstract words at Time 2, a post-hoc analysis of his reading performance was done on all the 160 words read at Time 2 (50 content/

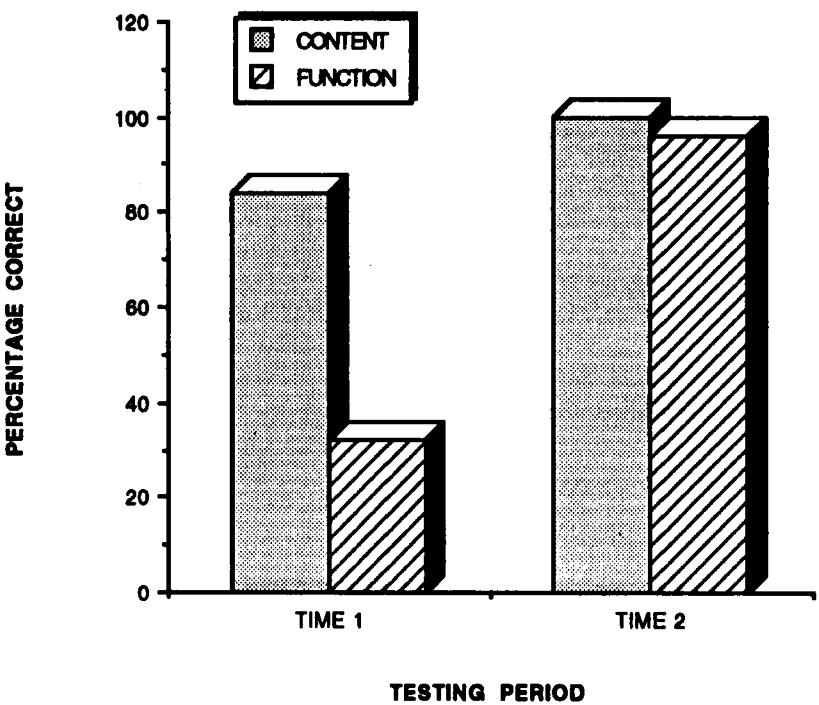

FIG. 2 Percentage correct content and function words read by RL at Time 1 and at Time 2.

function, 32 words from the words/nonwords list, and 78 regular/irregular). Concrete and abstract words made up 63 and 96 items of this set respectively and 1 target (TREAT read by RL as "threat") was considered ambiguous and omitted from the analysis. RL read correctly 60/63 (95%) concrete words and 92/96 abstract words (96%), showing no significant difference in performance as a function of item imageability.

Summary of Oral Reading at Time 2

The findings from Time 2 show a significant difference in RL's word reading relative to Time 1. Of the 160 words read at Time 2, RL read 150 (94%) correctly, showing significant improvement in overall performance relative to Time 1 ($\chi^2_1 = 26.3$, $P < 0.001$). Importantly, at this stage, his reading was not significantly influenced by part-of-speech nor by imageability, as had been the case at Time 1.

Error Classification

Although an error analysis on the 10 errors is not very informative, it is interesting to note that, at Time 2, no errors were purely semantic although 1 might be classified as a mixed semantic and visual error (the function word substitution HERE → "there"). The remaining 9 responses contained 8 visual errors and 1 derivational error.

Discussion of RL's Reading at Time 2

RL's pattern of reading at Time 2 is no longer consistent with the pattern of deep dyslexia. At 18 months post-onset, he produced no purely semantic errors, the defining characteristic of deep dyslexia. Along with the disappearance of semantic errors, the part-of-speech effect and the imageability effect also disappeared. The residual reading impairment that RL demonstrated at Time 2 is therefore limited to a deficit in nonword reading.

GENERAL DISCUSSION

The present paper describes a single subject, RL, who demonstrated an impairment in reading following a closed-head injury sustained in a motor vehicle accident. When tested initially at six months post-accident, RL showed all the symptoms associated with deep dyslexia. These included the presence of semantic paralexias in his oral reading at a rate exceeding chance levels, an impairment in nonword reading and an effect of word imageability and part-of-speech on his reading accuracy. On re-assessment at Time 2, 12 months later, RL's nonword reading showed no significant difference relative to Time 1 (word/nonwords and pseudohomophones list) although he did manage to read a few more nonwords correctly than at Time 1. In contrast with the nonword reading performance, RL's ability to read words improved significantly over the 12-month period from 72% accuracy at Time 1 to 94% accuracy at Time 2. Furthermore, although RL made 24% semantic errors at Time 1, of the 10 errors at Time 2, none was purely semantic. Along with this elimination of semantic errors, RL's reading performance was no longer significantly affected by part-of-speech nor by word imageability, as was the case at Time 1. Thus, the residual deficit in the RL's reading was restricted to an impairment in nonword reading.

Although there is considerable controversy in the literature regarding the number of routes by which normal readers can translate written words into sound, most views of single word reading agree that there are at least two routes through which orthography can be converted into phonology (Coltheart, 1982; Friedman, Note 4; Morton & Patterson, 1980; Newcombe & Marshall, 1980; Seidenberg & McClelland, 1989). In the one route, printed input activates its corresponding semantic representation directly and this representation is then used to access phonology. In the second route, phonology is accessed from print sublexically without intermediate access to semantics. Deep dyslexia is assumed to arise from some damage to both of these routes with the semantic errors, part-of-speech and imageability effects being generated by the impaired semantic route and the disruption in nonword reading being generated by the impaired sublexical or nonsemantic route. During recovery, then, either one or both of these routes might resolve. How might RL's recovery be interpreted in the light of such a two-route account?

One possible explanation is that the change in RL's reading is attributable to the improvement in the nonlexical reading route even though it was minimal and nonsignificant. It has been suggested that potential semantic errors may be inhibited by newly acquired phonological knowledge even if this knowledge is incomplete (Hillis & Caramazza, 1991; Newcombe & Marshall, 1980). Although the slight change in RL's nonword reading could potentially explain the reduction in semantic errors, it is unlikely that it could also account for the absence of the imageability and part-of-speech effects at Time 2. A more parsimonious account for the change is that, rather than RL recovering the ability to convert printed letters into sounds, he recovered the ability to carry out semantically mediated reading. Not only did the semantic errors disappear, indicating resolution of the lexical semantic route, but the part-of-speech and imageability effects, assumed to arise from the semantic reading route (Friedman, Note 4), were also absent on follow-up testing. On the basis of these findings, we conclude that the disappearance in semantic errors in RL's reading is attributable to the change in the reading route that accesses pronunciation from print via semantic representations. Although we have cast our discussion in terms of two routes, as discussed previously, some, but not all, researchers have argued for a third reading route in which orthography is connected to phonology and which contains word-specific representations. The improvement in RL's reading is also consistent with a change in this route. Thus, the elimination of the semantic errors, part-of-speech, and imageability effect may have come about because of the resolution of this lexical but nonsemantic route or because of recovery of the lexical semantic route. At present, there is no way of differentiating between improvement of the lexical semantic or the lexical nonsemantic routes. What is critical, however, is that the observed change occurred independent of equivalent change in the sublexical reading procedure.

Support for the finding that there may be selective recovery of the lexical route in deep dyslexia unaccompanied by significant change in the sub-lexical route comes from a study of a patient with a different, but related deficit. NC is a patient with deep dysphasia, a relatively rare form of repetition disorder characterised by semantic errors and an inability to repeat nonwords (Martin, Dell, Saffran, & Schwartz, in press). Over time, the semantic errors and the imageability effect in NC's single word repetition was no longer evident. The resulting pattern resembled that of conduction aphasia, a repetition deficit in which there are a high proportion of errors but a negligible number of semantic errors. The authors hypothesised that NC's deficits were attributable to an abnormally rapid decay of nodes in the semantic-lexical-phonological network, affecting both naming and repetition. The authors simulated NC's repetition impairment and the change over time using Dell's (1986) interactive spreading activation model of language production. When an abnormal decay rate was introduced to the network, the pattern of errors was remarkably similar to those observed in NC's repetition. Of interest is that the recovery over time was simulated by manipulating the decay parameter with gradual resolution of the decay rate to a level that produced a normal error pattern.

As with deep dysphasia, the change in performance in deep dyslexia over time has been successfully simulated by Plaut (1992) in a computational network in which orthography is mapped to semantics. In this network, there is no sublexical route and all reading takes place through semantic mediation. Initially, the network was lesioned in different locations in an attempt to simulate the variety of symptoms associated with deep dyslexia and to explore the effect of lesion location on the distribution of error type (Plaut & Shallice, 1993). The network was subsequently retrained and, although there was some variability in the degree of relearning following the different lesion locations within the model, the performance of the network improved substantially and recovered with retraining (Plaut, 1992). These results, however, are somewhat limited in that the network had only one functional reading route. An interesting extension of this work, then, might be to examine the effects of retraining in a fully implemented dual-route computational network in which both the sublexical and semantic routes are lesioned. This analysis would allow us to examine the resolution of deep dyslexia and the relative or differential change in the two reading routes when both routes are operating in tandem.

Returning to RL and the implications of the recovery pattern for theories of deep dyslexia, it is important to note that RL's major residual reading deficit was restricted to poor nonword reading. Such a deficit is characteristic of another form of acquired dyslexia, termed phonological dyslexia. Along with the nonword impairment, a relative deficit in functor word reading and a concreteness effect may sometimes be observed in phonological dyslexia (Friedman, Note 4). The critical distinguishing feature between the deep and phonological forms of dyslexia is the presence of semantic paralexias. Whereas these errors are present in deep dyslexia, they are absent in phonological dyslexia. At Time 1, RL showed the features of deep dyslexia, but because at Time 2 he produced no semantic errors and still showed impaired nonword reading, his reading is typical of phonological dyslexia. The overlap between these disorders has raised several questions about the relationship between deep and phonological dyslexia (Glosser & Friedman, 1990; Friedman, Note 4). Although these two disorders have been considered separable entities with different behaviours and neural substrates, one recent view is that they represent two points on the same continuum rather than representing two distinct and independent entities (Glosser & Friedman, 1990; Friedman, Note 4; Sartori et al., 1984). On this account, the sublexical orthographic to phonological connections are disrupted in both forms of dyslexia but the emergence of the overt symptoms depends on the severity of the semantic impairment (see also Morton & Patterson, 1980). With greater impairment to the semantic reading route, as in the case of deep dyslexia, those words that do not have rich semantic representations are compromised more readily than words with richly connected associations. Thus, for example, verbs and abstract nouns are most vulnerable, giving rise to the part-of-speech and imageability effects. Where the semantic impairment is minimal, only impaired nonword reading is observed. Evidence supporting the notion that deep and phonological dyslexia are parametric variations of the same basic phenomenon also comes from the finding that many patients evolve from deep to phonological dyslexia over time (Friedman, Note 4). The evolution of RL's reading pattern from deep dyslexia at Time 1 to phonological dyslexia at Time 2, when his overall reading accuracy improved, is consistent with the notion that these two deficits fall along a continuum of severity.

The finding that RL's reading pattern evolved over time and that the semantic errors disappeared is not that unusual or novel. There have been several documented reports of recovery from deep dyslexia although this does not always seem to be the case. GR, initially described by Marshall and Newcombe (1966; 1973) sustained brain damage in 1944 and, in 1988, when described by Barry and Richardson, his reading was still characteristic of deep dyslexia. Many patients with deep dyslexia, however, have shown improvement, many of them following therapy directed at remediating the reading deficit (SP—de Partz, 1986; GR—Glosser & Friedman, 1990; LR—Mitchum & Berndt, 1991). Since RL did not receive any direct intervention for his dyslexia (although he was certainly exposed to orthography in his day-to-day life), this cannot explain the improvement in his word reading. It seems, then, that the change in RL's performance is largely a result of spontaneous recovery. Because RL, like patient DV (Glosser & Friedman, 1990) and Leonardo (Sartori et al., 1984), did not receive any formal intervention, the spontaneous change in the semantically mediated reading route reflects one possible natural course of recovery from deep dyslexia. That the natural course implicates change in semantically mediated reading raises questions about the focus of therapy for patients with deep dyslexia. In many cases with deep dyslexia, the impairment in translating from letters to sounds was an obvious candidate for treatment and therapy directed at this impairment has been effective in many instances, as discussed earlier. It is possible, however, that the acquisition of sublexical letter-sound conversion procedures acts as a compensatory strategy, screening and editing out possible semantic errors rather than resolving the underlying problem per se, since the part-of-speech and imageability effects often persist. An alternative treatment approach, which might address the underlying problem more effectively and tap into the natural course of recovery, might involve remediation of the lexical (semantic or nonsemantic) route.

The observed change in RL's performance has several implications for theories of deep dyslexia. That the improvement occurred selectively provides additional support for functional dual-route theories of reading aloud, showing that recovery can occur differentially in the two routes. Although evidence for the functional recovery in deep dyslexia is now well documented, it remains unclear what neural structure is responsible for such change (Friedman, Note 4). This is partly explained by the fact that there is generally little agreement over the neural mechanism responsible for deep dyslexia in the first place. One view argues that deep dyslexia reflects the residual use of the partially impaired normal reading system, a system presumed to be located entirely in the left hemisphere (Morton & Patterson, 1980). An alternative, more controversial account is that deep dyslexia reflects the reading performance of a quite different system—that located in the right hemisphere (Coltheart, 1980d; Coltheart et al., Note 3; Saffran et al., 1980). Support for this latter view comes from several investigations, including the finding that a patient with only a right hemisphere shows a reading pattern similar to deep dyslexia (Patterson, Vargha-Kadem, & Polkey, 1989) and that on regional cerebral blood flow, there was greater activation of the right hemisphere in a deep dyslexic patient relative to other subjects (Coltheart et al., Note 3).

If the pattern of deep dyslexia comes about from right hemisphere reading as this view suggests, then, at Time 1, RL's reading would have been mediated by the right hemisphere. On this account, there are then two possible neural mechanisms for the change in RL's performance noted at Time 2. One possibility is that the usually impoverished right hemisphere acquired sufficient semantic knowledge, thereby eliminating the semantic errors as well as the part-of-speech and imageability effects in RL's reading. The other possibility is that the severely damaged left hemisphere improved, re-assuming the responsibility for reading. The right hemisphere view seems highly unlikely—one would not expect that the language-limited right hemisphere of adults would acquire new semantic knowledge such as the ability to read function words and abstract words. If indeed it were possible to see such a process of acquisition, one might expect all patients with deep dyslexia to show this pattern of recovery and this is clearly not the case (see GR of Barry & Richardson, 1988). Furthermore, if such acquisition were possible, then one might also expect to see the right hemisphere of split-brain patients showing this "recovery." This also does not seem to be the case; for example, there are reports of split-brain patients who, when tested seven years post-callosotomy, have shown only limited right hemisphere language capabilities (Baynes, Tramo, & Gazzaniga, 1992). It is unlikely, therefore, that the observed change in RL's performance is attributable to the acquisition of new knowledge by the right hemisphere.

The alternative explanation for the change is that the left hemisphere had recovered to a sufficient extent to subserve the reading of words. Thus, the right hemisphere reading producing the deep dyslexia served as a stop-gap measure, operating only until the left hemisphere had resumed functioning. Although the right hemisphere might have been engaged initially, its contribution was minimised when the left hemisphere had recovered sufficiently to be operational. Any theory that argues for right hemisphere reading in deep dyslexia must be able to account for the pattern of change observed in RL and, as is evident from the alternatives presented here, there does not seem to be an easy straightforward explanation. A more parsimonious account might be that the deep dyslexia reflects the residual functioning of the damaged left hemisphere. When the left hemisphere recovered to some extent, RL's reading improved. This explanation does not need to account for the change in hemispheric role over time and suggests that as the neural substrate recovered, so deep dyslexia evolved into phonological dyslexia.

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APPENDIX 1

Corpus of Errors made by RL on Nonword Reading

RL's error responses for Time 1 and Time 2 are shown. The errors to the words are classified as either visual (V), other (O) or semantic (S). + indicates correct performance.

A. Words Versus Nonwords

Target	*Time 1*	*Time 2*
Words		
session	machine (O)	+
clan	clam (V)	+
death	+	dread (V)
hour	house (V)	+
utensil	machine (S)	+
gist	hope (O)	+
accord	cord (V)	+
chasm	spasm (V)	spasm (V)
typhoon	harpoon (V)	+
gilt	guilty (V)	+
bard	bed (V)	bird (V)
abode	NR (O)	board (V)
Total correct	*21/32 (66%)*	*28/32 (88%)*
Nonwords		
keeting	kit	+
leceit	facelift	cease
skreet	streech	street/scream
dreed	streech	deem
tist	twist	twist
talute	salute	salute
ristory	machine	history
otensil	nine	+
gity	coloured	gaiga
bope	death	hope
durdery	drudgedy	drudgery
fuggler	fiddeley	fiddler
hamsel	damsel	hamstel
phasm	spasm	+
nomen	no female	noman
tession	mission	+
slan	scam	slam
nenom	vemos	vemon
jeath	dying	jet
dard	+	bark
doard	on board	board
fove	fower	four
ibode	NR	+
lyphoon	harpoon	leefon

Target	*Time 1*	*Time 2*
offort	effort	off fort
yindow	window	window
pilt	NR	bolt
iccord	cord	accord
guirit	guilt	gyrate
droduct	product	product
jable	stable	jabble
rour	hour	hour
Total correct	*1/32 (3%)*	*5/32 (16%)*

B. Pseudohomophones Versus Nonpseudohomophones

The first 11 pseudohomophones and the first 10 nonpseudohomophones were read at Time 1; + shows correct reading.

Target	*Time 1*	*Time 2*
Pseudohomophones		
akt	feign	NR
breth	NR	+
gard	NR	gar
sune	prune	sun
throan	NR	throw
streat	+	screen
owt	ower	hour
ize	ooze	zee
farsen	fern	+
ded	deed	+
klenz	NR	clean
----		
whife	—	+
eskaip	—	ekscape
burd	—	build
chuze	—	shoot
gerl	—	+
braik	—	+
groe	—	gr..
wun	—	+
merder	—	+
Total correct	*1/11 (9%)*	*8/20 (40%)*
Nonpseudohomophones		
phrone	faint	phone
sem	sew	seem
ploast	blast	plead
sheem	skim	scream
ume	NR	umm
dree	dress	gree

Target	Time 1	Time 2
gree	glass	+
cridge	NR	creds
leng	long	long
chawds	NR	shore
----		
sloser	—	closer
oin	—	un
thalk	—	tulk
pesh	—	plates
tains	—	train
groe	—	gr..
ekt	—	oak
scort	—	scored
bue	—	+
nuck	—	neck .. no tug
tuddy	—	tuggy
Total correct	*0/10 (0%)*	*2/20 (10%)*

APPENDIX 2

Corpus of Errors Produced by RL on Word Reading

RL's error responses for Time 1 and Time 2 are shown. The classification of the error is provided in brackets following the response. The errors are classified as visual (V), semantic (S), derivational (D), mixed (M), other (O) or no response (NR).

A. Concrete Versus Abstract

Target	Time 1	Time 2
Concrete		
accordion	music .. piano (S)	
Total correct	*27/28 (96%)*	
Abstract		
democracy	bureaucracy (M-V/S)	
mastery	mast (V)	
suffrage	rave .. rage (V)	
hint	NR (O)	
simile	smile (V)	
discord	the cause .. dis charge (V)	
unreality	to do with money (O)	
dogma	dog .. woman .. (S)	
fallacy	fallasty (V)	
Total correct	*19/28 (68%)*	

B. Part of Speech

(i) Nouns versus verbs

Target	*Time 1*	*Time 2*
Nouns		
guilt	guilty (D)	
Total correct	*29/30 (97%)*	
Verbs		
raise	fun .. raise funds (S)	
feed	eat, food (S)	
lose	weight (S)	
chose	choose (D)	
write	lend .. no. read (S)	
bought	at the (O)	
Total correct	*24/30 (80%)*	

(ii) Content versus function words

Target	*Time 1*	*Time 2*
Content		
make	made (D)	+
first	fist (V)	+
world	the will (O)	+
way	NR (O)	+
Total correct	*21/25 (84%)*	
Function		
both	one .. two (S)	+
upon	once upon a time (S)	+
most	more (M-V/S)	+
away	NR (O)	+
should	shoulder (V)	+
since	because (S-function)	+
those	at the (S-function)	+
each	at (S-function)	+
very	average (M-V/S-function)	+
any	at (S-function)	+
here	where (M-V/S-function)	there (M-V/S-function)
again	NR (O)	+
how	NR (O)	+
our	NR (O)	+
could	NR (O)	+
how	NR (O)	+
off	because (S-function)	+
Total correct	*8/25 (32%)*	*24/25 (96%)*

C. Regular Versus Irregular Words

Target	*Time 1*	*Time 2*
Regular		
treat	threaten/threat (V)	threat (V)
throng	shrong (V)	+
sherry	cherry (V)	+
check	checker (D)	+
sort	shorten (V)	+
shrug	shove, shug (V)	+
kept	dept .. depths (V)	+
barge	mushroom .. the ship (S)	+
trout	+	trough (V)
cult	guilty (V)	+
county	country (V)	+
trough	trought (V)	+
Total correct	*28/39 (72%)*	*37/39 (95%)*
Irregular		
borough	+	rough/burough (V)
debt	depth (V)	dept .. debtors (D)
gone	be gone .. being (S)	+
lose	shoes .. use. no (V)	loose (V)
shove	shovel (D)	+
gauge	thermometer/ temperature (S)	+
strewn	sew (V)	+
Total correct	*33/39 (85%)*	*36/39 (92%)*

D. High- Versus Low-frequency Words (from Seidenberg, 1985)

Target	*Time 1*
High frequency	
says	sentence (S)
face	washing (S)
chose	choose (D)
least	NR (O)
these	NR (O)
some	solemn (V)
heard	hearing (D)
corn	acorn (V)
lose	NR (O)
Total correct	*15/24 (63%)*

Target	*Time 1*
Low frequency	
worm	warm (V)
wand	wan (V)
hike	hitch-hiking (S)
fern	the plant (S-CO)
caste	cat (V)
phase	psalm (V)
wan	NR (O)
chore	NR (O)
bakes	cake (S)
dock	docks (D)
greed	greedy (D)
mode	NR (O)
rust	rus (V)
plaid	plate (V)
soot	NR (O)
Total correct	*9/24 (38%)*