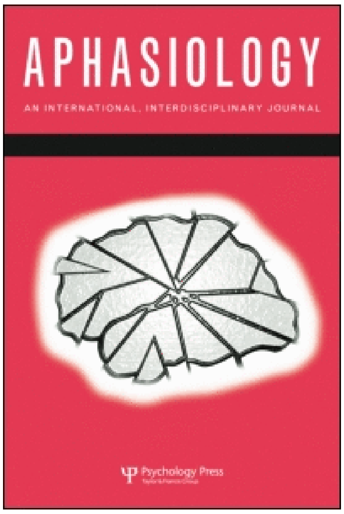

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More evidence for a continuum between phonological and deep dyslexia: Novel data from three measures of direct orthography-to-phonology translation

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More evidence for a continuum between phonological and deep dyslexia: Novel data from three measures of direct orthography-to-phonology translation

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Background: Over recent years a number of studies have suggested that phonological and deep dyslexia are not separate acquired dyslexias but actually reflect different points along a single continuum. Behaviourally this continuum was originally defined in terms of the graded presence/absence of the "symptoms" of deep dyslexia.
Aims: Given that orthography → phonology translation is core to phonological-deep dyslexia, it becomes critical to measure the degree and nature of any such direct phonological activation in these patients. Nonword reading accuracy has been the most commonly used measure of the status of direct orthographic → phonological activation but this measure can floor out in many phonological-deep dyslexic patients. In such circumstances, however, researchers have found evidence for some residual O→P function using reading tasks that do not require overt production—and these tasks might provide an important set of additional measures to test for a gradation of performance at the severer end of the phonological-deep dyslexic continuum.
Methods & Procedures: In the present study three tasks of this type (spoken-to-written nonword-matching, a novel word-matching task, and pseudohomophone reading) were developed and tested in a case-series of phonological-deep dyslexia (and made available in the appendices to this paper).
Outcomes & Results: As suggested from past studies, even patients with severely impaired overt nonword reading exhibited above-chance performance on the matching task and a pseudohomophone effect. The accuracy on these tasks varied in a graded manner across the case-series.
Conclusions: Two factors are key to this dyslexia continuum: the severity of phonological impairment and also the degree of interaction between semantic and impaired phonological representations, indicating that semantic representations become more central to reading in the face of phonological impairment.

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Keywords: Phonological dyslexia; Deep dyslexia; Nonword reading; Semantics; Orthographic-to-phonological conversion.

The defining characteristic of phonological dyslexia is a lexicality effect (reading accuracy greater for words than nonwords: Beauvois & Dérouesné, 1979). Nonword reading is typically impaired rather than abolished, although there is considerable variation in nonword reading accuracy (Berndt, Haendiges, Mitchum, & Wayland, 1996; Crisp & Lambon Ralph, 2006). Deep dyslexia is diagnosed when, in addition to severely impaired or abolished nonword reading, patients demonstrate a constellation of co-occurring symptoms (Coltheart, Patterson, & Marshall, 1980). These include the production of semantic (e.g., night is read as *"sleep"*), visual (e.g., badge → *"bandage"*), and derivational (e.g., edition → *"editor"*) errors. In addition, deep dyslexic patients exhibit effects of imageability and part-of-speech on their reading accuracy. Symptoms such as semantic paralexias and lexical-semantic influences have been taken as being symbiotically related to the patients' severely impaired nonword reading. For example, in the first seminal description of deep dyslexia, Marshall and Newcombe argued that even a minimal amount of direct translation between orthography and phonology would block semantic errors (Marshall & Newcombe, 1973). Likewise, direct phonological activation will also minimise the influence of lexical-semantic factors (encapsulated in the summation hypothesis: Hillis & Caramazza, 1995).

More recently, some researchers have argued that phonological and deep dyslexia represent the end points of a severity-based continuum (Friedman, 1996) with word and nonword accuracy varying in a graded manner (Crisp & Lambon Ralph, 2006). Indeed, these studies found that many of the symptoms of deep dyslexia were observed in patients with phonological dyslexia (e.g., imageability effects, morphological and visual reading errors, etc.) and there was no obvious dividing line to separate the two types of patient (Crisp & Lambon Ralph, 2006; Friedman, 1996). Therefore, when these dyslexias are understood in terms of a continuum, it is more appropriate to consider the remaining direct phonological activation in terms of degree rather than simple presence or absence.

Given that orthography → phonology translation is core to phonological-deep dyslexia, in order to understand the nature of this continuum better, it is important to increase the number and sensitivity of assessments used to estimate the degree of remaining O→P translation. This was the primary purpose of the present study. If the continuum hypothesis has merit, then the degree of O→P translation should vary in a graded fashion along the phonological-deep dyslexia continuum and, having established such measures, one could then explore whether the functioning of this direct translation is modulated significantly by other factors (e.g., the characteristics of words/nonwords or the influence of other representations). Nonword reading accuracy is the most commonly used "pure" measure of the status of direct orthographic → phonological activation as, by definition, nonwords cannot be supported by lexical-semantic knowledge. Although nonword reading accuracy can be very poor or at floor in phonological-deep dyslexia, this does not necessarily support the conclusion that direct phonological activation has been completely abolished. Such patients sometimes make phonologically related errors (word or nonword responses) to nonword targets—suggesting that there is at least some activation of phonology via sublexical orthography-to-phonology translation. Even omission errors do not imply an absence of phonological activation. As noted by Patterson (1978), in these circumstances it is possible that there is still some partial phonological activation[1] for nonwords but it is insufficient to support an overt spoken response. The possibility that there is partial phonological activation for nonword targets has been tested using three different methods and, as such, these might form the basis for quantifying the degree of direct phonological activation in phonological-deep dyslexia. The three methods are briefly reviewed below.

Patterson (1978; 1982) was the first to use spoken-to-written matching to investigate the degree and nature of any partial phonological activation. The rationale behind this technique is that although partial activation may be insufficient to support correct reading aloud, it should be easier to detect using a forced-choice paradigm. This could be for at least two reasons: (a) partial activation will bias a participant's response towards the target and away from the foils, thus pushing choice accuracy above chance even though the target phonology is only incompletely activated; and (b) it is also possible that hearing a word provides strong direct activation to the phonological system and this facilitates access to phonology from an orthographic input. Spoken–written nonword matching to patients with phonological-deep dyslexia was first used by Patterson (1978). In this study two patients with deep dyslexia were given a printed nonword and a choice of three spoken nonwords. The patients were asked to indicate which of the three alternatives was the correct pronunciation. There were two conditions, one in which the nonword alternatives were phonologically similar (e.g., *rean/reab/reat*) and the second in which the alternatives were phonologically dissimilar (e.g., *deet/whobe/bim*). In the first condition the two patients achieved 44% and 36%, placing one significantly above chance performance (at 33%) and the other statistically no better than chance. In the second condition, where very minimal phonological activation should enable patients to discriminate between the phonologically unrelated alternatives, they achieved 80% and 75% respectively. So although the patients were far from perfect on this simple matching task, their above-chance performance indicates that at least some partial phonological activation remained for the two patients. A similar investigation was reported by Berndt et al. (1996) where patients were given a single printed nonword and were asked to accept or reject a spoken nonword as the correct pronunciation (foils were close-phonological alternates). Out of their 11 patients, 7 scored significantly above chance on this task.

A second line of evidence for partial direct phonological activation comes from nonword priming studies. Buchanan, Hildebrandt, and MacKinnon (1994) investigated the influence of phonological priming on a lexical decision test. A deep dyslexic patient was given a target word (e.g., *chair*) preceded by either a pseudohomophone derived from an associatively related word (e.g., *taybul*) or an orthographic control nonword (e.g. *tarble*). The patient exhibited a priming effect such that response times were significantly shorter in the related condition than the unrelated condition. This result was replicated in two additional patients in a subsequent study (Buchanan, Hildebrandt, & MacKinnon, 1996). As argued by Buchanan et al., the significant priming effect indicates that some partial phonological activation for nonwords must

[1] "Partial phonological activation" could refer to "subthreshold" activation of the correct phonological target that cannot support overt reading but is sufficient to mediate performance on matching tasks. Alternatively, "partial" could refer to activating component subunits of the stimulus. These are hard to distinguish but we tend to the former given that these patients do not produce overt partial phonological responses but instead tend towards general omission errors.

have remained in these three patients despite their inability to read the nonwords aloud.

The third form of support for the notion of partial phonological activation in patients with deep-phonological dyslexia comes from investigations of pseudohomophone reading (initially studied in the first reported case of phonological dyslexia: Beauvois & Dérouesné, 1979). Pseudohomophones are nonwords in their orthographic form (e.g., frunt, gerl) yet their pronunciations correspond to a real word (i.e., "front", "girl"). Reading of these items is typically compared with nonpseudohomophonic control nonwords, which are nonwords both orthographically and phonologically (e.g., *frint*, *garl*). A pseudohomophone effect arises when the pseudohomophones are read significantly better than the control nonwords. Assuming that the control nonwords are appropriately matched to the pseudohomophones (see below), then the pseudohomophone effect must reflect a phonological-semantic boost provided by the familiar phonological (word) pattern and its associated meaning (see Discussion). As such, the effect provides evidence that these patients must be able to access phonology at least partially since it is only at the phonological level that the wordlikeness of the pseudohomophone emerges. Indeed in two cases of deep dyslexia-type readers, Buchanan and colleagues found a significant pseudohomophone effect (Buchanan, Kiss, & Burgess, 2000; Buchanan, McEwen, Westbury, & Libben, 2003), again suggesting some residual direct phonological activation (these cases, unusually, were also able to read a few nonwords correctly).

The results from these three different paradigms provide convergent evidence in favour of the notion that the status of direct orthographic → phonological activation is not a clear-cut, all-or-nothing phenomenon. These measures were developed for testing individual cases of either phonological (e.g., the pseudohomophone effect has been tested in phonological dyslexia) or deep dyslexia (e.g., the priming studies). As far as we are aware such measures have not been tested simultaneously across a varying set of phonological-to-deep dyslexic cases. If the continuum hypothesis is correct, then by doing this kind of parallel testing we should find evidence for a graded loss of function along the continuum—even when overt nonword reading accuracy has fallen to zero. In the current study, therefore, we investigated partial phonological activation in a case-series of 12 deep-phonological dyslexic patients, using three convergent techniques. The three paradigms were conducted in all the patients allowing us, for the first time, to compare the results across the same set of patients. The three tasks and some of the critical methodological issues are noted below:

1. Patterson's (1978) spoken-to-written nonword-matching task provides a simple method for assessing the degree of remaining phonological activation. Aside from the related "yes–no" matching task reported by Berndt and colleagues (1996), as far as we are aware the results from the first study have not been replicated since. Likewise, the same task has not been utilised in a full range of phonological-deep patients.
2. The second task involves a new experimental procedure. This "true synonym" test[2] is based on a standard spoken-to-written word-matching task: participants are required to indicate which of two written words is the same as a single word spoken by the examiner. Normally it is possible to discriminate between the two written words on the basis of either the words' meaning or their pronunciation.

[2]We thank Karalyn Patterson for suggesting the idea behind this novel task.

We attempted to use this task to measure the degree of direct phonological activation by forcing the participants to rely overwhelmingly on the pronunciation rather than the meaning of the words. This was achieved by picking words that had little, if any, semantic differences—i.e., true synonyms (e.g., *gift–present*, *rip–tear*). With no difference between the meaning of the words then the spoken and written words can only be matched on the basis of pronunciation and thus, this form of spoken-written word matching provides a measure of direct phonological activation.

3. The current study also investigated pseudohomophone reading. The true status of the pseudohomophone effects reported in the literature has been the subject of considerable debate stemming at least in part from controversy surrounding numerous methodological issues. It can be difficult to negotiate across this quagmire and therefore we highlight some of the key issues below.

NON-PSEUDOHOMOPHONIC OR CONTROL NONWORDS

One crucial factor for the validity of pseudohomophone testing is the adequacy of the control nonwords as a baseline comparator. There is debate over how best to construct the pseudohomophones and control nonwords to control for orthographic similarity. Two methods have been proposed: either change the same grapheme(s) of the base word to produce both the pseudohomophone and control nonword (e.g., weapon, wehpon, weepon: Berndt et al., 1996) or create sets of four nonwords by crossing two onsets and two rimes (e.g., hoap, joak, hoak, joap: Seidenberg, Petersen, MacDonald, & Plaut, 1996). In addition, there has been variation in the matching of pseudohomophones and control nonwords across other variables (e.g., orthographic neighbourhood size: Harm & Seidenberg, 2001). In the present study we ran both visual and rime/ body control nonwords for each pseudohomophone and the strings were matched for various orthographic neighbourhood measures.

VISUAL SIMILARITY

There is clearly a potential confound if pseudohomophones are more visually similar to real words than the control nonwords (e.g., phocks is a pseudohomophone of "*fox*" but it is a very atypical letter string in English with no orthographic neighbours, whereas fite is a much more "word-like" pseudohomophone for "*fight*"). In English, convincing pseudohomophone effects have largely been reported when the pseudohomophone is more orthographically similar to its corresponding real word. This issue has generated considerable debate and there are conflicting reports over whether visual similarity interacts with or, indeed, accounts for pseudohomophone effects (see Harm & Seidenberg, 2001; Howard & Best, 1996). We were not seeking to contribute to this debate in the present study but we took steps to control for visual similarity and used only more "word-like" pseudohomophones and control nonwords.

DIFFERENT ORTHOGRAPHIES

It is clear from the preceding two points that orthographic factors play a critical role in pseudohomophone effects. English, like other languages with relatively transparent orthography, is not best suited to pseudohomophone experiments in that phonological relationships are inevitably mirrored in orthography too. Consequently, once orthographic factors have been controlled for, it is very difficult to make words, pseudohomophones, and their control nonwords distinct from each other—minimising the likelihood of demonstrating significant differences between them. Given that our patients were all English readers, we were stuck with the limitations of this language. We note, however, that this limitation is not true for other orthographies where there is a greater separation between orthography and phonology. The multiple scripts of Japanese make it ideal to explore pseudohomophone effects because familiar phonological forms can be presented in a completely different script (e.g., kana transcriptions of nouns that are standardly written in kanji: Patterson, Suzuki, & Wydell, 1996; Sasanuma, Ito, Patterson, & Ito, 1996). Using this methodology, Patterson et al. (1996), found that patient KT exhibited substantial pseudohomophone effects in the context of very poor reading of even simple nonwords.

THE INTERACTION OF SEMANTICS AND PHONOLOGY

Patterson et al. (1996) found a major impact of both the concreteness/imageability and the frequency of the base word from which the pseudohomophones were derived. When the findings from their various word lists were combined, KT was significantly better at reading concrete over abstract pseudohomophones and poorer at reading pseudohomophones derived from low familiarity items. Other lexical-semantic variables associated with the base word therefore need to be considered.

INSTRUCTION EFFECTS

Monsell et al. (1992) suggested that normal readers are capable of "strategic dissociation" such that instructions, context, etc. may well alter the balance between lexical and sublexical spelling–sound translation. If participants are encouraged, explicitly or implicitly, to use a more lexical-semantic strategy, they will tend to block nonword production. Patterson et al (1996) reported that patient KT did perform differently on the same items depending on (a) explicit instruction (that all the items were words) or (b) implicit information (blocked rather than mixed item lists), with both having a clear facilitatory effect.

RESPONSE INTERPRETATION/ANALYSIS

Several studies (e.g., Howard & Best, 1996; e.g., Patterson & Marcel, 1992) have highlighted a possible discrepancy in the analysis of the patients' reading responses. This follows from the fact that occasionally patients produce the base word (e.g., "*front*") as a response not only to the pseudohomophone (e.g., frunt) but also the control nonword (e.g., frint). In a standard analysis, of course, the former response is counted as correct while the latter is incorrect (a "quasihomophone response"; Howard & Best, 1996). Alternatively, the patients' behaviour may simply reflect some kind of visual/phonological lexical capture of any nonword that is close to its corresponding base word. Previous studies have dealt with this in one of two ways: either treating quasihomophone responses as correct (Howard & Best, 1996) or by computing the rate of correct responses (i.e., *front* for frunt and *frint* for frint) as proportions of the total responses which are visually similar words (Patterson & Marcel, 1992). We present both kinds of analyses below.

In the current study we have attempted to address the above methodological issues as comprehensively as possible (see below for details). While we hope we have produced a valid and reliable pseudohomophone test for us and other researchers to use (see Appendix 3), it is clearly extremely difficult to avoid all the potential pitfalls we have described. It is critically important, therefore, to use a combination of different methods—as we have here—to evaluate the degree and nature of any partial phonological activation which occurs in phonological-deep dyslexia.

THE CURRENT STUDY

Participants

A total of 12 participants with the symptoms of phonological or deep dyslexia were recruited via local speech and language therapy services. They are the same cohort of participants reported previously (Crisp & Lambon Ralph, 2006). The patients were screened and recruited on the basis of demonstrating: (a) a lexicality effect, or (b) an imageability effect, or (c) production of semantic paralexias in reading aloud. The first 12 participants who fulfilled these inclusion criteria were recruited, and thus we avoided only including people with very marked deep dyslexic symptoms or relatively mild phonological dyslexia. Instead, the participants represent the full severity range of phonological-deep dyslexia. All the patients had acquired their dyslexia post-stroke, although this neurological diagnosis was not used as a method of selection. All were medically stable. There were 10 male and 2 female participants ranging in age from 40–83 years (mean age 59.4; *SD* 11.4). Months post onset varied between 6 and 156 (mean 53; *SD* 47.2). Unfortunately information from structural scanning is limited but left hemisphere infarction was confirmed by CT in eight cases.

Background assessments and findings

Basic information about each patients' reading disorder has been given before (Crisp & Lambon Ralph, 2006) and key aspects are simply summarised here. Each participant was asked to complete background assessments to identify deep dyslexic symptoms (semantic, visual, and morphological errors plus effects of imageability and lexicality on reading accuracy) and to measure the severity of the participant's acquired dyslexia. These were conducted over 6–10 one-hour testing sessions. The following tests were included within the battery:

1. Reading aloud matched lists of high- and low-imageability/frequency words: (a) a set of 96 items drawn from three levels of imageability and two levels of frequency, and (b) a set of 80 items with two levels of imageability and two levels of frequency (PALPA 31: Kay, Lesser, & Coltheart, 1992).
2. Reading aloud matched lists of words with varying syllable length. Participants read aloud the 30 words in a shortened semantic battery in which syllable length is varied but frequency and age-of-acquisition are controlled (one, two, and three or more syllables: derived from Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000).
3. Reading aloud inflected/affixed words to elicit morphological errors. Participants read aloud 30 inflected/affixed words that were matched for the frequency and imageability of the stem (modified version of PALPA 34: Kay et al., 1992).

4. Nonword reading: (a) 24 monosyllabic nonwords varying in length from three to six letters (Test 36: Kay et al., 1992); (b) 30 nonwords derived from and matched (for letter length and numbers of orthographic and phonological neighbours) with the items in (2) above; (c) 48 nonwords derived from and matched (for letter length and numbers of orthographic and phonological neighbours) with the low frequency items in 1(a) above.

All error responses were analysed and coded. Responses were categorised as visual/phonological errors when 50% of the letters in the response were present in the stimulus (following the criterion proposed by Morton & Patterson, 1980). The results of the reading assessments from the 12 participants are shown in Tables 1a (accuracy) and 1b (errors). The participants are ordered from left to right by increasing word reading accuracy in all the tables and figures.

All participants performed outside the normal range on nonword reading. This was accompanied by a considerable range of word reading skills; some participants performed within the normal range on some word reading tests (e.g., DB, TH) although none was completely unimpaired. The performance of others (e.g., LR, MM, RJ) was at or close to floor on some of the assessments. All participants made at least some derivational errors (e.g., clouds → "cloudy") and some visual errors (e.g., winter → "window", value → "valley"). All but one of the participants (DB) exhibited an imageability effect in word reading. In summary most, if not all, of the symptoms traditionally associated with deep dyslexia were present in all participants even though only LR, MM, RJ, and NS produced a significant proportion of semantic paralexias. Readers are referred to our earlier paper for a more detailed discussion of these and other related results (Crisp & Lambon Ralph, 2006).

Experimental investigations

Spoken-written nonword-matching task

Method. This investigation was a replication based on the original experiment reported by Patterson (1978). There were two conditions. In the first, 30 nonword triads were created in which the alternatives were phonologically/orthographically similar; 10 of the triads differed in initial letter/sound only (e.g., *deet, keet, leet*), 10 differed in the vowel (e.g., *tose, tase, tice*), and a further 10 differed in final letter/sound (e.g., *faip, faig, faib*). The test items are listed in Appendix 1. The participants were given a single printed nonword while the researcher read aloud the three nonwords of the triad. Their task was to select the spoken alternative that corresponded to the printed stimulus. In the second condition there were a further 30 nonword triads but the alternatives were chosen to be maximally different from the target and each other (e.g., *deet, whobe, bim*).

Results. Table 2 summarises the participants' performance. In the first condition with phonologically similar choices, all the participants performed outside the control range, although 8 of the 12 were significantly better than chance. In the second condition with phonologically dissimilar choices, 11 of the 12 participants performed above chance and indeed 3 of them achieved performance within the normal range (MR, BN, and DB). This improvement was quite marked in a number of individual cases

TABLE 1a
Background reading assessments

Participant	*Max. Score*	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*	*Controls* (normal cut-off)*
Age (years)		58	58	40	64	83	51	72	52	60	66	48	61	
Months post-onset		156	120	18	31	14	96	28	42	68	28	31	6	
Word reading:														
Imageability × Frequency (I×F) list:														
• *all items*	*96*	13	25	36	42	64	66	69	70	71	73	86	88	✧
• *high imageability*	*32*	11	21	24	26	29	31	31	30	28	28	32	31	✧
• *low imageability*	*32*	0	1	3	4	15	14	14	17	20	16	28	26	✧
PALPA 31: *high imageability*	*40*	16	21	24	25	33	37	37	34	39	31	***40***	39	39.9 (39.4)
low imageability	*40*	0	2	1	13	18	27	26	27	32	27	37	***39***	39.5 (38.1)
Semantic battery words	*30*	10	20	8	24	22	29	24	30	28	27	29	29	✧
PALPA 34: morphological complexity	*30*	1	1	7	13	18	12	24	23	24	23	24	29	✧
Nonword reading:														
PALPA 36	*24*	2	0	2	8	13	7	8	11	2	9	6	14	22.9 (19.9)
Semantic battery nonwords	*30*	0	0	1	7	10	4	4	7	3	7	6	21	29.3 (27.4)
Nonwords for I × F list	*48*	0	0	0	9	16	3	4	8	0	4	11	19	45.7 (42.9)

PALPA= Psycholinguistic Assessments of Language Processing in Aphasia (Kay et al., 1992).
*Re. control data: where the figures are known they are given as follows: first figure = mean, bracketed figure = cut-off at 2 standard deviation below the mean.
✧normal performance assumed to be at ceiling on these easy tasks.
Scores shown in italic bold type are within the normal range.

TABLE 1b
Reading error analysis

Participant	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*
Accuracy (total words = 388)	12.1	21.6	28.9	47.7	67.5	68.3	76.3	76	78.1	74	91	95.1
Type of error:												
Semantic	5.9	4.9	4.6	0	0	1	0	0	0	0.3	0	0
Visually/phonologically-related words	12.6	10.3	13.4	11.3	5.9	11.3	12.9	9	8.2	4.6	5.2	1.5
Visually/phonologically -related nonwords	2.3	0.8	12.4	28.1	14.9	1.8	3.6	7.7	7.7	5.7	0.8	2.1
Morphological	2.1	5.9	5.2	2.6	2.1	4.4	2.1	1.8	2.6	9	2.3	0.8
No response	36.3	37.4	22.4	1.8	0	6.2	3.4	0.3	0.8	0.3	0	0
Other	28.6	19.1	13.1	8.5	9.5	7	1.8	5.2	2.6	6.2	0.8	0.5

This error analysis is based on all the words read by the participants (collapsing across tests, $N = 388$). Reading accuracy and the rate of different error types are expressed as a percentage of trials.

TABLE 2
Nonword-matching results

Participant	*Max. score*	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*	*Controls* (normal cut-off)*
Phonologically similar triads	*30*	10	***18***	***18***	11	***27***	16	***18***	***24***	***18***	***19***	13	***27***	29.8 (29)
• initial difference (*deet/ keet/ leet*)	*10*	6	7	4	3	10	7	9	10	7	8	2	10	
• vowel difference (*tose/ tase/ tice*)	*10*	1	3	6	2	8	5	3	8	7	4	5	8	
• final difference (*faip/ faig/ faib*)	*10*	3	8	8	6	9	4	6	6	4	7	6	9	
Phonologically dissimilar triads	*30*	***19***	***26***	***27***	13	***28***	***26***	***30***	***29***	***22***	***28***	***26***	***30***	29.7 (28.1)
Total	*60*	***29***	***44***	***45***	24	***55***	***42***	***48***	***53***	***40***	***47***	***39***	***57***	59.5 (57.8)

Re. control data: first figure = mean, bracketed figure = cut-off at 2 standard deviation below the mean.
Total scores shown in italic bold type are significantly above chance ($p < .001$ one tailed binomial exact test).

and was significant for the group as a whole, $t_{(11)} = 6.2$, $p < .001$. One of the participants, RS, had significant auditory processing difficulties (word deafness, see below), which clearly impacted on his ability to perform the task.

Discussion. This experiment replicated Patterson's (1978) finding that even patients with deep dyslexia do not have an absolute elimination of direct phonological activation from print. Although such patients demonstrate very poor or abolished overt nonword reading, some residual activation of the target phonology remains as shown by their above-chance performance at least with the dissimilar triads (e.g., LR, MM, RJ; see Table 1). It seems most likely that this follows from the fact that this remaining phonological activation is inadequate to drive a specific, overt spoken response but is sufficient to boost performance on a forced-choice discrimination to above chance—especially when there are considerable phonological differences between the alternative pronunciations offered by the examiner.

If anything, we suspect that this procedure may underestimate the degree of any remaining partial activation of phonology direct from orthography: Patterson's (1978) nonword-matching task clearly makes significant demands on phonological/verbal working memory (the patient is provided with a three item nonword list to choose from). Although one could consider other methodologies to reduce such concurrent demands, this version is more directly comparable to nonword reading in that each trial contains one written nonword at a time (unlike a version in which a single spoken form is matched to three written nonwords which might reduce the load on working memory).

"True" synonym task

Method. The "true" synonym test is, as far as we are aware, a new experimental procedure. As noted above, this test is based on a standard spoken-to-written word-matching task. In each trial the patient is required to choose which of two written words matches the spoken word provided by the examiner. The logic behind the test is that, under normal circumstances, the match can be made on the basis of word meaning or phonology. By reducing the difference between the meanings of the written word alternatives, this balance shifts increasingly in favour of phonology for the discrimination. In the limit, with no differences in meaning between the words (i.e., by using "true" synonym pairs), the patient is forced to rely entirely on phonological differences. In this way the task provides an indirect measure of the remaining orthography $\rightarrow$ phonology activation.

The test consists of 35 pairs of highly synonymous written words, which we selected to be as close to "true" synonyms as possible (e.g., *gift–present, rip–tear*). Possible synonym pairs were rejected where we felt that there were any subtle differences in meaning or sense. In addition, we used external sources of information to confirm our choices (using data on synonym pairs from Wilding & Mohindra, 1983): synonyms were only selected if they (a) had received high similarity ratings and (b) did not show marked directional asymmetry (on the judgement task controls were asked to perform). The majority of the synonyms identified in this way varied quite considerably in their (Celex combined lemma) frequency—which might bias the choice made by patients. Rather than restrict our test to only those pairs with relatively similar frequency, we probed both words of each pair on separate occasions. The test was constructed so that half the written pairs had the lower frequency item first and the other half had the higher frequency item first. Administration was counterbalanced over two sessions, probing half the lower frequency and half the higher frequency items in each session. Test materials are provided in Appendix 2.

Given that even true synonyms have very different phonological forms, this task is trivially easy for normal participants. However, as reported below, we found that four of the patients performed surprisingly badly at this task. As a further test of our assumption that this was due to the high synonymy of the word pairs, we conducted a follow up experiment with these four patients who fell below 90% correct. For this experiment each of the items in the original true synonym test was paired with another real word that was both semantically and phonologically unrelated. The new word pairs were matched for imageability and frequency. The task instructions were identical. Administration was counterbalanced over twp sessions so that synonymous words did not occur within the same session. If it was the high synonymy of the original pairs that made the task so challenging for the patients, then we expected to see a significant boost in performance by relaxing the relatedness of the word pairs in this way.

Results. Table 3 summarises the participants' performance. All the participants performed significantly above chance on the true synonym test (all binomial $p < .01$). Since the synonyms are difficult to distinguish on the basis of meaning alone (because of their very high semantic similarity), it seems likely that the participants must have been activating phonology—at least partially—in order to perform above chance. Thus this novel task provides converging evidence that even in very poor, deep dyslexic readers, some direct orthography → phonology activation remains.

That said, four patients fell below our liberal 90% criterion: LR, MM, RJ, and RS. Table 1 confirms that these were the worst nonword readers (and, with the exception of RS, they were deep dyslexic). One could imagine that this might reflect some kind of poor auditory perception of the examiner's spoken probe. To test this we asked all the patients to complete the ADA minimal pair discrimination task (Franklin, Turner, & Ellis, 1992), which is a relatively sensitive measure of accurate phoneme recognition. The patients' scores on this test are shown at the bottom of Table 3. While a number of the patients did have auditory processing deficits, it is clear that this could not account for the level of performance on the true synonym task (indeed LR, the worst reader, had perfect performance on the minimal pair task). The exceptions to this were patients RS and NS who had poor performance on any task that required them to process spoken words. For the remaining patients the word pair follow-up task confirmed that the poor true synonym performance was due to the patients' over-reliance on word meaning (rather than phonological activation) to complete the task: once the semantic relatedness of the word pairs was relaxed, their scores

TABLE 3
"True" synonym results

Participant	*Max. score*	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*
'True' synonyms	*70*	47	52	62	50	66	69	70	67	67	70	70	70
Word pair test	*70*	66	67	69	56	-	-	-	-	-	-	-	-
ADA minimal pair discrimination*	*40*	40	31	36	22	30	18	31	36	39	37	39	40

*Control data: mean = 39.4, cut-off (at 2 *SD* below the mean) = 37.5.

improved dramatically. In conclusion, this task provides us with another estimate of the patients' remaining orthography → phonology activation. As with the Patterson spoken-written nonword-matching task, it indicates that for deep dyslexic patients O→P activation is poor but not completely abolished.

Pseudohomophone reading

Method. For this investigation participants were asked to read aloud mixed lists of words, pseudohomophones and two forms of non-pseudohomophonic control nonword. There were 192 items and these were counterbalanced across sessions so that each pseudohomophone and its control words were not presented in the same session. The items within each session were randomised with the caveat that no more than three of the same word/nonword type occurred in sequence. Participants were told "some of the items are words, some are made up and others might not look like words but they do sound like words". The test items are listed in Appendix 3.

In the development of the pseudohomophone test we attempted to address the methodological issues (outlined in the Introduction) as comprehensively as possible. Only pseudohomophones that were produced by normal participants with at least 80%, but more often 100%, accuracy were used. We used two control nonwords for each pseudohomophone: first, a "body" control such that both the pseudohomophone and the control nonword had the same letters after the onset (e.g., *frunt/prunt*) and second, a visual similarity control, ensuring that the pseudohomophone and the control nonword were equally different from the base word by changing the same element(s) of the base word for each (e.g., *frunt/frint*). We avoided very visually dissimilar pseudohomophones (such as *phocks* and *phude*). We orthogonally varied both the imageability (high/low) and frequency (high/low) of base words, as much as possible (given the many other methodological constraints) and matched the resulting four cells by number of phonological neighbours, number of orthographic neighbours, head/body type frequency count and its square root.

Results. The patients' reading accuracy for each word/nonword type is detailed in Table 4. When their ability to read aloud the pseudohomophone and the visually similar control nonword was compared (see also Figure 1), 8 of the 12 participants showed a significant or borderline pseudohomophone effect. The effect was highly reliable for the group as a whole, $t_{(11)} = 4.2$, $p = .001$. When pseudohomophone reading was compared against body control nonwords then a very similar pattern emerged: again eight patients (seven of the same as identified with visual control nonwords) and the group as a whole demonstrated the effect, $t_{(11)} = 7.9$, $p < .001$. In our previous study (Crisp & Lambon Ralph, 2006) we found that all bar the mildest patient (DB) exhibited a significant effect of imageability on word reading accuracy. While this was replicated for the group as a whole in the words included in this pseudohomophone effect, $t_{(11)} = 3.42$, $p = .006$, the effect was only significant for five of the individual patients. It seems most likely that this reflects the fact that imageability could not be varied as strongly in this test because of the other methodological demands (each word has to have a possible, visually plausible pseudohomophone pair and be matched to other items for the various psycholinguistic variables). In their previous study of Japanese phonological dyslexic patients, Patterson et al. (1996) found that success on pseudohomophone reading was modulated by the imageability of the base word. We replicated this finding at the group level, $t_{(11)} = 3.38$, $p = .006$, but, again using this test, the effect was

TABLE 4
Pseudohomophone test results

Participant		*Max. score*	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*	*Mean (SD)*
Real words	**Total**	*48*	7	15	24	28	34	44	40	38	42	40	46	47	33.8 (12.8)
	high imag'	*24*	6†	12†	17†	13	17	24†	22	22†	22	22	23	24	18.7 (5.7)†
	low imag'	*24*	1†	3†	7†	15	17	20†	18	16†	20	18	23	23	15.1 (7.4)†
Pseudohomophones	**Total**	*48*	2	4	8	21	30	19	19	25	12	16	15	34	17.1 (9.8)
	high imag'	*24*	2	4†	7†	13	15	11	9	13	9†	10	9	16	9.8 (4.2)†
	low imag'	*24*	0	0†	1†	8	15	8	10	12	3†	6	6	18	7.3 (5.8)†
Visual control nonwords		*48*	0	0*	1*	12**	23	5**	4**	16**	2**	9*	16	37	10.4 (11.2)**
Body control nonwords		*48*	0	0*	3	12**	21**	5**	9**	17*	4**	6**	9	30	9.7 (9.0)**
Number of quasihomophone	Visual control nonwords		3	4	4	4	4	9	8	3	8	3	4	1	4.6 (2.4)
responses	Body control nonwords		0	0	0	1	0	0	0	0	1	0	0	0	0.2 (0.4)

Control data: first figure = mean, bracketed figure = cut-off at 2 *SD* below the mean.

Significant pseudohomophone effect (pseudohomophone reading > nonword reading) denoted by ** (individual data χ^2, group data t-test: *p*-values < .05). Borderline effect (0.10 < *p* < .05) denoted by single *.

Significant imageability effect indicated by † (individual Fisher exact, group data *t*-test: *p*-values < .05)

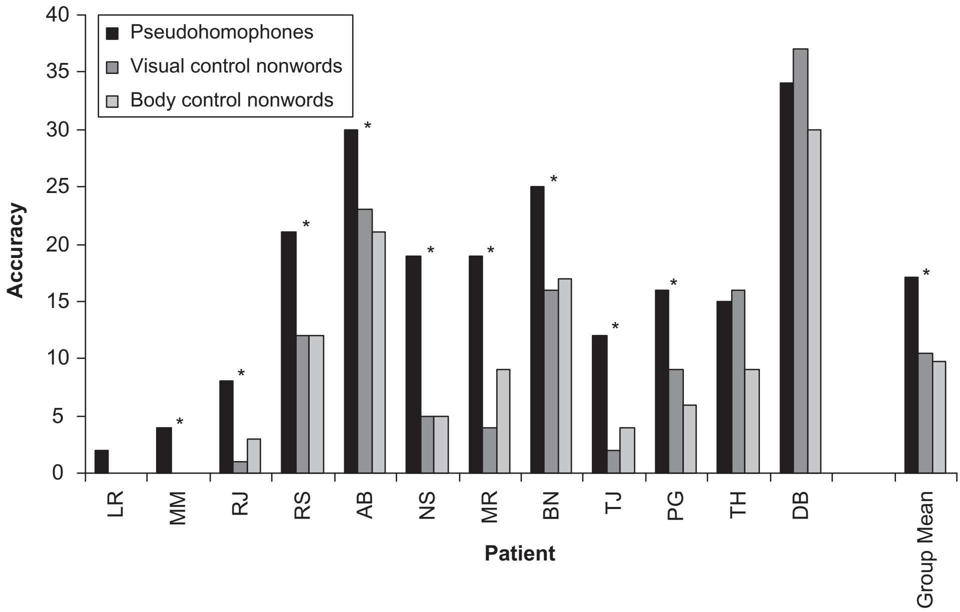

Figure 1. Reading accuracy for pseudohomophones vs control nonwords. *Indicates pseudohomophone effect (see Table 4 for details).

not powerful enough to produce significant differences at the individual level for the majority of cases.

In summary, using a new test of pseudohomophone reading (that attempted to control for the many methodological issues raised by other researchers), we found pseudohomophone effects throughout the entire continuum of phonology-deep dyslexia. Only the very severest patient (LR) and the mildest (TH and DB) failed to exhibit a significant difference. It is possible that this simply reflects floor and ceiling effects, respectively. In addition, we found evidence that the interaction between word meaning and phonological representations plays an important part in the emergence of the pseudohomophone effect (as proposed by Patterson et al., 1996). These findings are discussed in more detail in the General Discussion below.

As noted in previous studies, many of the patients produced some quasihomophone responses to the visual control nonwords (e.g., frint "front": Howard & Best, 1996; Patterson & Marcel, 1992). These researchers suggested that quasihomophone responses might reflect some form of visual or phonological "lexical capture". If this occurs at the visual end of the reading system, then this kind of response might undermine the notion that pseudohomophones reflect evidence for residual phonological activation of nonwords in people with phonological-deep dyslexia. Of course, the strong overlap between orthographic and phonological representations in English means that the source of these responses is hard to pin down (see Introduction). We attempted to address this issue via three further forms of analysis: (a) compare the rate of quasihomophone responses to visual vs body control nonwords; (b) recode the pseudohomophone reading data according to Patterson and Marcel's (1992) method for dealing with quasihomophone responses; and (c) analyse the phonological and orthographic overlap between stimulus and patient's response.

The numbers of quasihomophone responses to visual and body control nonwords are summarised at the bottom of Table 4. Two things are immediately apparent from these figures: all patients produce at least some quasihomophone responses but they are almost exclusively made to the visual control nonwords and not to the body control nonwords (the difference across the two types of nonword was significant: Wilcoxon, $Z = 3.1$, $p = .002$). This striking difference reflects the fact that (as summarised in Table 1b for word targets) the patients commonly produce visually/phonologically related word errors to word and nonword targets. When this occurs to visual control nonwords then one of the nearest orthographic/phonological word neighbours is almost inevitably the base word, and thus it is difficult for the patients' response to correspond to anything other than a quasihomophone. This does not apply to the body control words and so, although they also make visually/phonologically related real-word responses to these items, the base word is much less likely to be a close neighbour and so the rate of quasihomophone responses is near zero. In effect, the production of quasihomophones reflects a conjunction of the patients' tendency to produce visually/phonologically related word responses and the construction of the visual control nonwords (i.e., highly visually similar).

The question that then arises is the same as that posed and addressed by Patterson and Marcel (1992): Is the pseudohomophone effect truly evidence for partial phonological activation of nonwords or does it reflect some kind of visual "lexical" capture? Although the possibility of lexical capture applies equally at the phonological or orthographic ends of the reading system, if we were to assume that all of the lexical (correct or incorrect) responses of the patients were driven by orthographic capture then the phonological basis of pseudohomophone effects would be brought into doubt. Patterson and Marcel tested this possibility by expressing pseudohomophone reading accuracy as a proportion of all visually similar reading responses [correct / (correct + visual lexical errors)]. If the pseudohomophone effect reflects visual lexical capture alone then this proportion should be similar for pseudohomophones and their visual nonword controls. On the other hand, if at least a part of the pseudohomophone effect reflects phonological lexical capture then the calculated proportions should be higher for pseudohomophones than control nonwords. We repeated this analysis for each of the patients reported here and the proportions for words, pseudohomophones, and visual control nonwords are summarised in Table 5. When the pseudohomophone effect is expressed in this way then we find a very similar pattern of results as those reported by Patterson and Marcel. Of the eight patients identified as exhibiting a pseudohomophone effect in the standard analysis (those in the middle section of the phonological–deep dyslexic continuum), seven showed a significant/borderline difference using the revised measure. Again, when treated as a group, the patients exhibit a significant pseudohomophone effect, $t_{(11)} = 5.0$, $p < .001$.

The final additional analysis looked again at the substantial number of word errors produced to all word/nonword targets by the patients. If their improved pseudohomophone reading was really underpinned by a purely visual form of lexical capture then the patients' closely related word errors should show greater orthographic than phononological overlap with their target. For this analysis "closely related" was defined as any response that was only one phoneme and/or letter away from the target. These closely related word errors were classified into three subgroups: (i) both orthographic and phonological neighbours (e.g., saice→ "sauce", purse → "nurse"); (ii) orthographic but not phonological neighbours (e.g., frunt → "fruit",

TABLE 5
Applying the Patterson and Marcel analysis to the pseudohomophone reading data

Participant	*Calculation*	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*	*Mean (SD)*
Real words	*A (Correct responses)*	7	15	24	28	34	44	40	38	42	40	46	47	
	B(correct responses plus visual lexical errors)	7	16	26	35	38	46	47	40	43	40	46	47	
	A / (A+B)	1	0.94	0.92	0.8	0.89	0.96	0.85	0.95	0.98	1	1	1	0.94 (0.07)
Pseudohomophones	*A (Correct responses)*	2	4	8	21	30	19	19	25	12	16	15	34	
	B(correct responses plus visual lexical errors)	4	5	16	25	33	28	25	34	19	19	19	41	
	A / (A+B)	0.5	0.8*	0.5†	0.84†	0.91	0.68*	0.76*	0.74	0.63*	0.84†	0.79	0.83	0.74* (0.13)
Visual control nonword	*A (Correct responses)*	0	0	2	12	23	5	4	16	2	9	16	37	
	B(correct responses plus visual lexical errors)	4	8	14	22	28	24	25	29	19	18	29	39	
	A / (A+B)	0	0*	0.14†	0.55†	0.82	0.21*	0.16*	0.55	0.11*	0.5†	0.55	0.95	0.38* (0.32)

*Proportion significantly different between pseudohomophones and visual control nonwords, $p < .05$ (Fisher exact for individual data or paired *t*-test for group data);

†borderline difference – $0.10 < p < .05$.

TABLE 6
Classification of "lexical capture" errors produced by the patients

Participant	*LR*	*MM*	*RJ*	*RS*	*AB*	*NS*	*MR*	*BN*	*TJ*	*PG*	*TH*	*DB*	*Mean proportion for whole group*
Target and error related:													
Orthographically and phonologically	8	13	27	24	14	42	40	25	33	16	26	13	0.65
Orthographically only	0*	1	2*	1*	1*	2*	5	2*	1*	2*	3*	2	0.05*
Phonologically only	4*	5	10*	11*	11*	17*	11	11*	16*	15*	14*	6	0.30*

*Denoted significant difference in rate of orthographic-only vs phonologic-only related errors ($p < .05$; group t-test, individual data Fisher exact).

mouth → "month"); and (iii) phonological but not orthographic neighbours (e.g., rorn → "fawn", girl → "curl").

The results of this error classification are summarised in Table 6. Given the considerable consistency between orthography and phonology in English (see Introduction), it is unsurprising that the vast majority of errors were both phonologically and orthographically related (65% for the group as a whole). The notion that pseudohomophone effects might be an artefact of visual lexical capture is not supported by the distribution of orthographic-only vs phonologic-only related word errors. As can be seen in Table 6, on average 30% of the remaining errors fell into the phonologically related group. The differential rate for these two types of word errors was significant in 9 of the 12 patients and for the group as a whole, $t(11) = 11.0$, $p < .001$. While this pattern of results does not discount the possibility of lexical capture at the orthographic end of the reading system, it makes it clear that at least some lexical capture does arise in phonology. Given that the patients make word errors to both nonwords as well as word targets (see Tables 1b and 5), these phonologically related errors provide further evidence for partial phonological activation in phonological-deep dyslexia.

GENERAL DISCUSSION

This study developed and tested three alternative measures to overt nonword reading in order to assess the degree of remaining direct orthographic → phonological activation in patients with phonological-deep dyslexia. The first investigation replicated Patterson's (1978) original study and found that all but one of the patients (whose performance was compromised by word deafness, as shown by poor performance in ADA nonword minimal pairs) performed above chance on two tests of spoken-to-written nonword-matching. This would suggest that there is some remaining, partial phonological activation of nonwords that is enough to push a three-alternative, forced-choice discrimination above chance but insufficient to generate an overt production. The second investigation utilised a novel, "true synonym" task. In a spoken-to-written word-matching paradigm, patients had to rely more on phonology than meaning by reducing the semantic difference between the word alternatives to a minimum (by picking 'true' synonyms). Despite this, all patients performed above chance, again suggesting that some partial sublexical or direct orthography → phonology mapping remained. The final investigation utilised pseudohomophone reading to probe for phonological activation of nonwords. Using a new version of the task that attempted to control for the many methodological factors noted in the literature, we found that 9 of the 12 exhibited a pseudohomophone effect on at least one version of the task (and the effect was highly reliable across the group as a whole). Floor and ceiling effects prevented the other patients (the most severe and mildest cases) from demonstrating the same difference. In summary, the primary goal of this study was met: all three tasks provide converging and consistent evidence for the notion that patients with phonological-deep dyslexia have some degree of direct orthography → phonological activation. Even the severest cases in the series—those with deep dyslexia—demonstrated evidence for partial phonological activation of nonwords – even though they were unable to read them aloud. The theoretical interpretations of these findings are considered briefly below. Here we note that the partial phonological activation observed across the case series, opens up the possibility that therapeutic interventions could try to target this aspect of partial performance and thereby boost this aspect of reading behaviour.

The present study provides further evidence in favour of the notion that phonological and deep dyslexia are not separate entities but represent points along a severity continuum (Crisp & Lambon Ralph, 2006; Friedman, 1996). There is no sensible dividing line along this continuum by which the patients can be segregated into two exclusive groups; instead their performance varies in a continuous fashion. In addition to word and nonword reading accuracy shifting in a graded manner along this continuum, performance on the three measures of partial phonological activation also varied in the same way. This is also consistent with our previous study of these patients (Crisp & Lambon Ralph, 2006) and provides additional support for the notion that the reduced ability to activate the patients' impaired phonological system is key to understanding phonological-deep dyslexia (Patterson & Marcel, 1992; Patterson et al., 1996).

Previous studies of deep dyslexia have disagreed about the status of phonological activation in nonword reading. Marshall and Newcombe (1973) argued that there was no direct activation for nonwords and suggested that the emergence of semantic paralexias reflected the same problem—as one might expect even a small amount of direct phonological activation to block semantic errors (later called the summation hypothesis: Hillis & Caramazza, 1995). In contrast, using tasks that did not require overt reading, other researchers have found evidence for phonological activation of nonword targets (Buchanan et al., 1994, 1996, 2000, 2003; Patterson, 1978). Studying the full range of phonological-deep dyslexia provides an important context for this debate. As noted by Patterson (1978), accurate overt nonword reading is demanding and more so than matching or discrimination tasks. The present study showed that this variation across phonological and reading measures can be observed throughout the full phonological-deep dyslexia continuum. At the severe end the deep dyslexic patients could, at best, read a small handful of simple nonword stimuli correctly, yet their performance on the matching tasks was above chance. At the other end of the scale the mild phonological dyslexic patients performed at ceiling on these simple matching tasks, but their overt nonword reading still fell below the normal range.

The very poor yet non-abolished phonological activation available to the deep dyslexic patients was underlined by the new true synonym judgement task. The task of discriminating between pairs such as gift and present is trivial for normal participants because even though there is little, if any, difference in terms of meaning, there is no overlap phonologically. Despite the gross phonological contrast, the deep dyslexic participants performed poorly on the task (though above chance—in a very similar way to the nonword-matching task). The importance of the high semantic similarity of the synonym pairs in producing this result was confirmed by the follow-up task in which each synonym was paired with an unrelated word (in both meaning and phonology). Under these conditions the patients' performance improved dramatically.

In the face of phonological impairment, word meaning seems to play an important, perhaps even an enhanced, role in patients with phonological-deep dyslexia. There are several lines of evidence in favour of this proposal. First, as noted above, the semantic distance between the words directly influences the patients' ability to match spoken and written words—which is not the case for normal participants. Likewise, in our previous study we found that all bar the mildest patient demonstrated a significant influence of imageability on reading accuracy (Crisp & Lambon Ralph, 2006). Although imageability effects can be demonstrated in normal reading (Strain, Patterson, & Seidenberg, 1995), it is only found in reaction times and is limited to low-frequency words with inconsistent spelling to sound patterns—making the influence of imageability in phonological-deep dyslexia a much stronger, enhanced effect in terms of both degree (affecting accuracy) and pervasiveness (affecting all types of word). The third indication for the importance of meaning in these cases is the interaction of the pseudohomophone effect with imageability. The best demonstration of this is still the Japanese phonological dyslexics reported by Patterson and colleagues (1996). This may be due, at least in part, to the fact that their study was able to separate orthography and phonology completely by utilising the different scripts used in Japanese. The imageability manipulation used in our pseudohomophone task was limited by the other methodological constraints (e.g., varying frequency, producing good nonword control items, balancing for visual/orthographic factors, etc.) Even so, the pseudohomophone effect exhibited by two of the patients was also influenced by the imageability of the baseline word. This influence, albeit small in English, was sufficient for the effect to be statistically reliable for the group as a whole. This suggests that word meaning plays a role in the lexical capture process that underpins pseudohomophone effects (see below). All three examples indicate that there is a critically important, perhaps enhanced role of word meaning in these patients. This might follow if semantic memory provides a secure representation which, when engaged by the damaged reading system, can be used to stabilise the activation arising in the patients' compromised phonological system. This may follow from the strong, efficient phonological–semantic interaction in the premorbid language system (used for speech production and comprehension). It is also possible that the influence of semantic representations might increase during the period of plasticity-related recovery demonstrated by many patients after CVA, thereby enhancing the semantic-phonological interaction. This possibility is supported by recent explorations using the PDP "triangle" model of reading (Welbourne & Lambon Ralph, 2007). These investigations demonstrated that immediately following damage to the phonological portion of the network, reading performance collapsed for all types of word and nonword. Following a period of plasticity-related recovery, the model partially recovered reading performance overall while lexicality and imageability effects emerged during this recovery period—coming to match the size of the effects exhibited by the patient case-series reported in this paper and by Berndt et al. (1996). As suspected from the patient results, these increased lexicality and imageability effects arose in the model from an enhanced role of semantic representations in reading aloud. Given that nonwords do not have meaning, this increased semantic-phonological interaction can only benefit real words, especially those with robust (concrete) meanings.

The pseudohomophone effect demonstrated in the vast majority of our patients adds further examples to the many others reported in the literature (Beauvois & Dérouesné, 1979; Berndt et al., 1996; Patterson & Marcel, 1992; Patterson et al., 1996). This study also makes it evident that the effect can be found across the full severity range of patients with phonological-deep dyslexia, only being absent in patients with reading close to floor or ceiling (for evidence of pseudohomophone effects in other deep dyslexic cases, see Buchanan et al., 2000; for evidence of pseudohomophone effects in other deep dyslexic cases, see Buchanan et al., 2003). The pseudohomophone effect, along with the many lexical (formal) errors made by the patients to word and nonword targets, would follow from a process of "lexical capture" (Funnell & Davison, 1989). This was defined by Patterson and Marcel (1992) as "the elements of an unstable pattern (nonword) are captured or over-ridden by a stable pattern (word) containing some or many of the same elements" (p. 266). Lexical capture could arise at the level of orthography and/or phonology, and may also involve interaction of these representations with word meaning to form a stable activation pattern (see above). Although orthographic lexical capture may be a factor in the effect, this study found positive evidence in favour of the proposition that phonological lexical capture is a major contributor as well. First, following the logic of the task, pseudohomophones are undifferentiated from their nonword controls with respect to orthography but change status (equivalent to words) at the level of phonology. Thus it is only when some form of (at least partial) phonological activation arises that the reading system can benefit from pre-existing, additional representations about the pseudohomophones; the resultant activation corresponds to a familiar phonological representation, a familiar articulation and can invoke the underlying interaction between the familiar phonological form and its meaning (Patterson et al., 1996; Sasanuma et al., 1996; Seidenberg et al., 1996; Welbourne & Lambon Ralph, 2007). Second, analysis of the patients' lexical (formal) errors indicated that a large minority (30%) were closely related to their targets with respect to their phonological rather than orthographic overlap (the vast majority, 65%, were both orthographically and phonologically related). If one assumes that lexical errors in these patients are driven by the same lexical capture process that underpins pseudohomophone effects, then it is evident that phonology provides a key locus of lexical capture.

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APPENDIX 1

Nonword-matching test materials

Condition 1: Phonologically/orthographically similar triads

deet	keet	leet	WI
lail	lile	lole	V
foach	**feach**	fitch	V
faip	faig	**faib**	WF
hean	tean	thean	WI
klorn	glorn	**plorn**	WI
tose	**tase**	tice	V
krawn	krawb	krawt	WF
kide	fide	mide	WI
whebe	whobe	**whabe**	V
veabs	veags	**veats**	WF
fleb	freb	sleb	WI
wace	**nace**	yace	WI
klack	kluke	klake	V
nall	**jall**	zall	WI
yad	jod	**yed**	V
loag	**loat**	loak	WF
sleath	skeath	steath	WI
streep	streen	**streed**	WF
lorse	**porse**	vorse	WI
bame	bem	bim	V
fos	**fod**	foj	WF
reab	rean	**reat**	WF
drale	**drowl**	drial	V
kield	kiled	keld	V
noke	nobe	nofe	WF
dape	**dake**	dase	WF
reg	rel	rem	WF
mirt	virt	**sirt**	WI
vate	**vit**	vot	V

WI = initial position altered, V = vowel altered, WF = final position altered.

Condition 2: Phonologically/ orthographically dissimilar triads

deet	whobe	bim
lail	strist	queem
bry	**feach**	steath
loag	vork	**faib**
hean	lile	grib
reab	kluke	**plorn**
whebe	**tase**	fitch
krawn	noak	striffed
kide	plitch	loak
tose	streen	**whabe**
drale	krawb	**veats**
fleb	trean	mide
slitch	**nace**	telf
klack	teafed	lole
neaf	**jall**	blit
fos	drief	**yed**
streep	**loat**	drial
sleath	freb	tice
nall	veags	**streed**
geed	**porse**	sprute
bame	rean	krawt
bork	**fod**	leet
lorse	fide	**reat**
wace	**drowl**	prief
kield	friv	spalt
noke	lemf	mebe
merp	**dake**	lemz
reg	glell	pud
dape	trow	**sirt**
bince	**vit**	dreal

APPENDIX 2
"True synonyms" test materials

Synonyms

sum	total	answer	reply
happiness	joy	heap	pile
ale	beer	soup	broth
couple	pair	bravery	courage
error	mistake	amount	quantity
killer	murderer	leap	jump
parcel	package	cash	money
spade	shovel	muddle	confusion
rip	tear	sweat	perspiration
thief	robber	banquet	feast
aid	help	reluctance	unwillingness
wages	salary	liberty	freedom
grave	tomb	despair	hopelessness
riches	wealth	odour	smell
prison	jail	witchcraft	sorcery
start	begin	writer	author
gift	present	story	tale
trap	snare		

Word pairs

amount	issue	**quantity**	nonsense
effort	**answer**	**reply**	fate
beer	pipe	crook	**ale**
begin	interest	**start**	name
text	**confusion**	build	**muddle**
wall	**couple**	breath	**pair**
courage	vision	**bravery**	enamel
recognition	**despair**	above	**hopelessness**
feast	pencil	**banquet**	crow
freedom	message	**liberty**	grammar
cigar	**grave**	glove	**tomb**
scale	**help**	move	**aid**
steel	**joy**	poet	**happiness**
dye	**jump**	**leap**	polish
killer	certificate	procession	**murderer**
discussion	**mistake**	**error**	opponent
money	sea	black	**cash**
package	waist	fleet	**parcel**
tribe	**pile**	**heap**	roll
present	link	ash	**gift**
prison	train	**jail**	flag
deduction	**reluctance**	**unwillingness**	attempt
vote	**smell**	echo	**odour**
prince	**soup**	chestnut	**broth**
spade	crow	**shovel**	bark
line	**story**	honour	**tale**
sum	witness	**total**	merit
sweat	basket	referee	**perspiration**
dust	**tear**	cement	**rip**
thief	medal	**robber**	tar
trap	sock	**snare**	pan
lump	**wages**	**salary**	border
track	**wealth**	canteen	**riches**
witchcraft	fleet	welcome	**sorcery**
tool	**writer**	**author**	code

APPENDIX 3
Pseudohomophone test materials

HiImHiFr	*psh*	*cnw (body)*	*cnw (visual)*	LoImHiFr	*psh*	*cnw (body)*	*cnw (visual)*
TEETH	teath	peath	terth	FAR	phar	slar	thar
STREET	streat	skreat	streft	REACH	reech	neech	relch
BLOOD	blud	glud	blid	FREE	phree	dree	stree
GREEN	grean	drean	grenn	DEAL	deel	beel	derl
CHURCH	chirch	shirch	charch	COST	kossed	possed	vossed
WHITE	wite	dite	wote	RANGE	rainge	wainge	rawnge
FACE	faice	saice	fance	MONTH	munth	nunth	minth
MOUTH	mowth	nowth	mooth	FRONT	frunt	prunt	frint
GIRL	gerl	merl	garl	FORCE	forse	porse	ferse
FIGHT	fite	pite	fibe	TYPE	tipe	kipe	tupe
CAMP	kamp	pamp	jamp	TERM	tirm	kirm	tarm
BALL	borl	dorl	burl	ONCE	wunce	lunce	rance
HiImLoFr	*psh*	*cnw (body)*	*cnw (visual)*	LoImLoFr	*psh*	*cnw (body)*	*cnw (visual)*
SWAMP	swomp	slomp	swemp	THWART	thwort	strort	thwert
CHALK	chork	thork	chark	DEBT	dett	rett	dest
JUICE	jooce	vooce	jonce	MEEK	meak	neak	menk
PURSE	perce	serce	porce	BLEAK	bleek	gleek	bleck
GHOST	ghoast	whoast	ghorst	LEASE	leace	weace	leate
SCOUT	skout	slout	swout	SCORN	skawn	stawn	skarn
HOUND	hownd	townd	hoind	TENSE	tence	kence	tenge
PIG	pigg	tigg	pagg	PSALM	sarm	darm	jarm
CHEESE	cheeze	speeze	cheeve	VERB	vurb	jurb	varb
LAWN	lorn	rorn	larn	GERM	jirm	mirm	horm
TOMB	toom	poom	torm	CULT	kult	tult	pult
CALF	carf	tarf	caif	CURSE	kirse	firse	mirse

HiIm = high imageability, LoIm = low imageability, HiFr = high frequency, LoFr = low frequency, psh = pseudohomophone, cnw = control nonword, body = share body, visual = visually related.