

DOES LETTER-BY-LETTER READING INVOLVE THE SPELLING SYSTEM?

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Abstract—WARRINGTON and SHALLICE (*Brain* 103, 99–112, 1980) proposed that letter-by-letter readers can no longer access the visual word-form system, and read by using the spelling system ‘in reverse’. Contrary to their suggestion, this paper presents the case of a letter-by-letter reader who appears to use quite different strategies in word reading and spelling. Reading and spelling are both impaired, but they appear to be impaired in different ways. Most strikingly, the patient’s spelling errors consist largely of phonological regularizations—indeed there is little evidence that he has any lexical spelling knowledge available—whereas there are virtually no regularizations amongst his reading errors. These are largely visual paralexias and letter misidentifications. It is suggested that this pattern is more easily explained in terms of compensatory mechanisms that access the reading lexicon than by use of the spelling system ‘in reverse’.

INTRODUCTION

LETTER-BY-LETTER reading is a form of acquired dyslexia in which patients appear to read single words by identifying one letter at a time. Consequently, reading is extremely laboured, and reading time increases in line with the number of letters in a word. For example, patients have been reported who take over 16 sec on average to read three- and four-letter words, and almost 50 sec to read seven- and eight-letter words [24]. There are at least two important questions that have been asked about letter-by-letter reading. The first concerns the nature of the reading impairment; at what stage has the normal reading process broken down? Several recent papers provide interesting discussions of this issue [4, 15, 18, 28, 30, 33]. The second question concerns the compensatory strategies used by letter-by-letter readers that produce such a distinctive pattern of performance. Although these two questions are obviously related, it is the nature of the compensatory strategies used in letter-by-letter reading that provides the main focus for the present investigation.

First of all, it is important to point out that the compensatory strategies employed in letter-by-letter reading involve the use of letter *names* rather than letter *sounds*. In a ‘shallow’ orthography, there is no need to distinguish letter names from letter sounds. In a ‘deep’ orthography such as English, however, a particular phoneme may be associated with a number of different letters in the context of different words. Consequently, since we generally cannot make unique reference to a particular letter by a sound, each letter is given its own name. There are, of course, acquired dyslexics whose compensatory strategies involve the use of letter sounds. Such patients, who are generally referred to as ‘sound-by-sound’ readers or ‘surface dyslexics’, attempt to read words on the basis of sublexical

phonology [21]. Letter-by-letter readers, in contrast, employ compensatory strategies that resemble those which a normal reader might use when attempting to recognize a word that is spelled orally.

According to WARRINGTON and SHALLICE [35], patients employ a letter-by-letter strategy because they are unable to use the visual word form system during reading. In order to compensate, they employ a radically different set of procedures from those normally used in visual word recognition. Once a representation of the names of all the letters that comprise the word has been built up, reading proceeds via the *spelling* system. Exactly how this might take place has never been fully specified, although the most explicit account can be found in SHALLICE and MCCARTHY [31]. Normally, of course, it is the job of the spelling system to produce a sequence of letters as *output*. However, these authors suggest that the spelling process can also work 'in reverse', and can accept sequences of letter names as *input*. Although not explicitly stated, it appears that the authors assume that the link between the letter names and a word's representation in the spelling system is bidirectional. Then, once the appropriate entry in the spelling lexicon is located, it can be used to address an entry in the phonological output lexicon if a spoken response is required.

In contrast, PATTERSON and KAY [24] argue that letter-by-letter readers *are* capable of using the visual word-form system. What they have lost is the ability to *access* this system in the normal way. Skilled readers can pick up letter information across several letter positions simultaneously. Letter-by-letter readers, however, are obliged to access the word-form system via *serial* rather than parallel letter identification. This process, like the reverse use of the spelling system in Warrington and Shallice's account, is seen as being a time-consuming operation which is directly related to the number of letters in a word.

The ability to recognize a word from its letter names is a skill which normal readers can apply without undue difficulty. Consequently, the compensatory strategies that letter-by-letter readers employ do, almost certainly, reflect a normal meta-linguistic function. Nevertheless, PATTERSON and KAY [24] do not provide any *a priori* justification for the claim that the word form system can be accessed via serial letter recognition, and WARRINGTON and SHALLICE [35] provide no *a priori* justification for the claim that the spelling system can operate in reverse.

Perhaps the main reason for the popularity of Warrington and Shallice's account are the parallels between the reading performance and the spelling performance of individual letter-by-letter readers. If these patients are indeed using reverse spelling to enable them to read, then one would expect that the way in which they read words should reflect the way in which they spell words. Up until recently, this has always proved to be the case [24, 26].

Patterson and Kay, for instance, showed that letter-by-letter readers could be separated into Type 1 and Type 2 readers. Type 1 letter-by-letter readers such as patients M.W. and C.H. were good spellers, but experienced severe letter recognition difficulties. Since they are good at spelling, it follows from Warrington and Shallice's account that they should be able to read words accurately whenever they can correctly identify the letters. This turned out to be the case. Type 2 letter-by-letter readers such as T.P. and K.C., by contrast, are generally better at letter recognition than Type 1 patients, but often read words incorrectly even when they have identified the letters appropriately. Consistent with Warrington and Shallice's view, T.P. and K.C. were also poor spellers who produced the same types of errors in reading that they made in spelling. Their spelling errors generally preserved the phonological features of the word's spoken form, and are thus characteristic of surface dysgraphia [2]. For

example, T.P., whose spelling performance is described in detail by HATFIELD and PATTERSON [14] spelt 'nephew' as NEFFUE, and 'biscuit' as BISKET. Moreover, these two patients also made phonological errors in *reading*. T.P., for instance, read 'gone' as JOAN, and 'city' as KITTY. Reading errors such as these are, of course, characteristic of surface dyslexia [21].

In order to explain the pattern of impairment observed in T.P. and K.C., Patterson and Kay were forced to argue that both Type 2 patients were suffering from two distinct deficits, one of which led to phonological errors in *reading*, and one of which led to phonological errors in *spelling*. They acknowledged (p. 434) that WARRINGTON and SHALICE [35] could offer a much more parsimonious explanation of this pattern of performance. According to the reverse spelling hypothesis, a letter-by-letter reader who produces phonological errors in *spelling* would be expected to show a similar pattern of impairment in *reading*. As Shallice and McCarthy state:

TP and KC spelled with an over-reliance on the typical sound-to-spelling correspondence of English. . . . If this spelling process were "reversed" then one would indeed expect that patients with the appropriate double deficits would try out pronunciations rather than words *per se*. [30, p. 367]

What Warrington and Shallice would find difficult to explain, therefore, would be a letter-by-letter reader whose impairment in *spelling* was not reflected in his or her *reading* performance. On the other hand, the existence of such a patient is exactly what would be predicted from PATTERSON and KAY [24]. Recently, RAPCSAK *et al.* [27] have described a Type 1 letter-by-letter, P.T., whose *spelling* is severely impaired, and who makes phonologically appropriate *spelling* errors. When she makes errors in *reading*, however, they come about as a result of letter misidentifications and are visual errors (e.g. 'aisle' > 'assail') rather than phonological regularizations. This is not consistent with the reverse spelling hypothesis [31, 35]; if P.T. makes phonological errors in *spelling* then she should also make phonological errors in *reading*. Furthermore, the reverse spelling account also has problems in explaining why, when she is asked to identify orally spelled words, P.T. makes hardly any errors even though her oral *spelling* is as severely impaired as her written *spelling*. Rapsack *et al.* conclude that Patterson and Kay's account of letter-by-letter reading provides a much better explanation of P.T.'s performance than the reverse spelling hypothesis.

Nevertheless, P.T. was a Type 1 letter-by-letter reader whose word recognition problems reflected problems in visual letter recognition. It therefore remains possible that the *reading* of Type 2 letter-by-letter readers, who find it difficult to recognize words even when they have successfully identified all the letters, may be dependent upon the *spelling* system. In order to investigate this issue, we report below a detailed examination of the performance of a Type 2 letter-by-letter reader whose *reading* and *spelling* also appear to be impaired in very different ways.

CASE REPORT

P.D. is 32-years-old, right-handed, and lives in the north-east of England. In November 1982, he suffered a left thalamic haemorrhage which partly ruptured into the lateral ventricle (see Fig. 1). It was caused by a very small arteriovenous malformation (AVM) lodged in the posterior thalamus, extending into the brain stem, and fed from the left-posterior cerebral artery. The AVM was not excised because of the technical difficulty and extreme risk of the procedure. His clinical notes at that time show that he had a right homonymous hemianopia with sparing of the macula and a right hemiparesis with right hemianesthesia. On follow-up, 1 year later, these problems had not resolved, and mild expressive dysphasia was also recorded. We began to see P.D. in November 1987. His visual difficulties and hemiparesis remain, but he has only residual word-finding difficulties, affecting proper names in

particular, in spontaneous conversation. Despite the visual field deficit, his contrast sensitivity is normal [25], as is Snellen acuity (6/6).

His performance is also within the normal range on tests of object recognition, memory and spoken language. His score of 43 on the Warrington Recognition Memory Test for Faces [34] is normal. On tests devised by HANLEY *et al.* [13], he was good at recognizing the faces and names of celebrities who have become famous since 1985, as well as those who were famous before 1980. He has an auditory digit span of six items, and he shows good overall performance, and a strong effect of phonological similarity, in serial recall of auditorily presented letters. He made six errors out of 80 on the non-word repetition test from the PALPA battery [19], which is within the normal range, and he made only one error out of 80 on a test of auditory lexical decision. He also scored 30/30 on a test of phonological awareness [3]. His score of 15 on the Graded Naming Test [20] represents 'average' performance, and he scored 40/40 on the Spoken Word Picture Matching Test from the PALPA battery. He also scored 36/36 on Humphreys and Riddoch's object decision task.* Taken together, these results suggest that P.D. does not suffer from visual agnosia, amnesia, a short-term memory deficit, or a disorder of spoken language.

INVESTIGATION OF READING AND SPELLING

Letter recognition

P.D. was given several tests of letter recognition from the PALPA battery [19]. He made 1 error out of 26 in *lowercase to uppercase matching* (matching a lowercase 'l' to 'l' rather than to 'L'). He made one error, which he self-corrected, in *spoken-letter to written-letter matching*. He also made one error out of 26 in *naming uppercase letters* ('H' > 'E') and one error in *naming lowercase letters* ('f' > 'i'). He also produced the appropriate sound for all the letters that he correctly named, with the exception of the letter 'X' (which he sounded out as if it were 'Zuh'). Errors in letter recognition are consistent with previous studies of letter-by-letter reading. Nevertheless, P.D.'s impairment is slight and is reminiscent of the relatively mild deficit shown by the Type 2 letter-by-letter reader T.P. rather than the severe problems experienced by the Type 1 patient C.H. who made letter recognition errors on approximately 50% of trials [24]. Although we have not made any formal comparisons, we have never noted any differences in P.D.'s ability to recognize either letters or words when the font size increases.

Is P.D. a letter-by-letter reader?

P.D. reports that since his illness he finds reading extremely difficult and no longer reads for pleasure. This is because of the length of time that it takes him to read each word. As a result of these spontaneous complaints, we have given him several hundred single words to read aloud under formal testing conditions. On average, he takes 6.3 sec to read three- to four-letter words, 11.7 sec to read five- to six-letter words, and 25.9 sec to read seven- to eight-letter words. Both the overall latencies, and the relationship between reading time and letter length, are consistent with letter-by-letter reading. Table 1 provides a direct comparison with PATTERSON and KAY's [24] cases. Table 1 indicates that it is the performance of T.P. that most closely resembles that of P.D. Furthermore, T.P. frequently made errors in reading words even when she had correctly identified the letters. This is also the case with P.D. Whenever he is specifically asked to name the letters in a word, he is almost always accurate, even when he subsequently comes up with the wrong word. The reading problems that both patients encounter go well beyond letter recognition difficulties, therefore, and confirm that like T.P., P.D. should be thought of as a Type 2 letter-by-letter reader.

We have ascertained that the effect of word length on reading times is not due to the

*G. Humphreys kindly allowed us to use this test.



Fig. 1. CT scan taken on admittance showing the effects of left thalamic haemorrhage.

Table 1. P.D.'s reading performance in comparison with the four letter-by-letter readers studied by PATTERSON and KAY (1982)

Patient	Letter naming errors(%)	Reading latencies (sec)		
		3 4*	5 6*	7-8*
T.P.	4	7.6	11.2	15.5
P.D.	4	6.3	11.7	25.9
M.W.	10	12.8	18.4	24.3
K.C.	17	10.5	18.6	26.0
C.H.	50	16.9	32.4	47.5

*Number of letters in words.

number of syllables, rather than the number of letters, that a word contains. Thus P.D. was given a set of 24 five-letter words from the PALPA battery which comprise eight words of one syllable (e.g. 'blood', 'watch', 'bread', 'flash'), eight words of two syllables (e.g. 'hotel', 'metal', 'beard', 'angel'), and eight words of three syllables (e.g. 'radio', 'union', 'ivory', 'enemy'). The words are matched for imagability and lexical frequency. P.D. took an average of 13.4 sec (SD = 14.7) to read the words of one syllable, 8.2 sec on average (SD = 4.9) to read the two-syllable words, and 11.2 sec (SD = 6.4) to read the three-syllable words. This indicates that there is no effect of number of syllables on the length of time he takes to read a word when number of letters is held constant.

P.D.'s performance on a same-different matching task [12] provides more specific evidence about the way in which he processes sequences of letters. In this task, one word is presented immediately above another and the subject must decide, as quickly as possible, whether or not the two words match. When the two-words differed, the different letter was either at the beginning (e.g. cork-work), middle (e.g. firm farm) or end (e.g. plum plug) of the words. Unlike normal subjects, P.D. took significantly longer to match words which contained six letters (e.g. health) than words which contained five letters (e.g. lemon) or four letters (e.g. cork). Furthermore, P.D. took significantly longer to detect a mismatch when it occurred at the *end* of a word than when it occurred at the beginning or in the middle. Normal subjects [12], and our control subject, by contrast, took longest when the mismatch occurred in the *middle* of the word. These results show that P.D. processes the letters in a word from left-to-right in serial order, and support the view that letter-by-letter readers have great difficulty in processing letters in parallel [24]. KAY and HANLEY [18] provide complete details, including means and standard deviations, and a fuller discussion of P.D.'s performance on this task.

A further characteristic of letter-by-letter readers is that they encounter greater problems when confronted by a cursive script. For example, WARRINGTON and SHALLICE [35] report that J.D.C. and M.L. both found it more difficult to read words when the letters were joined together. P.D. shows a similar pattern of performance. On two separate occasions, he was given the same list of 72 words to read from ELLIS *et al.* [11]. The first time they were typed, and the second time they were handwritten in a cursive style. Twelve months separated the two presentations. P.D.'s performance dropped from 54/72 (75%) correct with the typed list to 39/72 (54%) correct with the handwritten words. In addition, there were 29 words that he read correctly on both occasions. Of these, 24/29 were read more quickly when typed, whereas only 5/29 were read more quickly when handwritten.

P.D. shows no difference in the accuracy with which he reads high and low frequency

words. On ELLIS *et al.*'s [11] list where the words are matched for number of letters and imagery, P.D. was correct on 18/24 words of 'high' frequency (e.g. 'gun', 'land', 'river', 'doctor'), 17/24 words of 'medium' frequency (e.g. 'tea', 'scat', 'bread', 'pencil'), and 19/24 words of 'low' frequency (e.g. 'zoo', 'plum', 'tulip', 'bucket'). He did, however, read the high frequency words slightly quicker (mean = 5.5 sec, SD = 6.1) than medium frequency words (mean = 7.8 sec, SD = 6.1) and low frequency words (mean = 8.6, SD = 9.4). He showed similar effects with high imagery and low imagery words when asked to read 30 high imagery (e.g. 'drum', 'onion', 'radio', 'school') and 30 low imagery words (e.g. 'clue', 'realm', 'moment', 'tribute') from the PALPA battery. The words were controlled for frequency and phonological regularity. He was correct on 21/30 high imagery words, and 19/30 low imagery words. He was, however, slower to read the low imageability words.

One final point is that P.D. showed no evidence of being able to access the meanings of words that he was unable to identify overtly, when they were presented for short durations. Unlike some letter-by-letter readers [9, 32], P.D. performed no better than chance at categorizing written words as *living* or *non-living*, when they were presented to him for approximately 1 sec each. In this respect, P.D. resembles the four letter-by-letter readers of PATTERSON and KAY [24], and five letter-by-letter readers examined by BUB *et al.* [4], who also failed to show any evidence of rapid comprehension of written words.

To summarize, P.D. takes an extremely long time to read each word. His performance is directly influenced by letter length, and his reading speed is consistent with the number of letter recognition errors that he makes when compared with other letter-by-letter readers. He finds reading more difficult when the letters are joined together in cursive script. Performance on matching tasks suggests that he perceives letters serially from left to right, rather than in parallel. Therefore, P.D. appears to conform to virtually all of the criteria that are typically associated with letter-by-letter reading. Since his letter recognition performance is only mildly impaired, and since he fails to identify words even when he can accurately report the letters, it is clear that P.D. is a Type 2 rather than a Type 1 letter-by-letter reader.

The nature of P.D.'s reading errors

P.D. was able to read approximately 70% of all the words that we gave him accurately. We have categorized a total of 105 of his reading errors. Of these, 94 can be regarded as visual paralexias, 10 are neologisms, and one might be considered a possible semantic error ('bridge' → PATH). Twelve of the paralexias arose from letter misidentifications, 10 of them involving the letter 'b' (e.g. 'bread' → 'DREAD', 'rib' → 'RID', 'bump' → 'PUMP', 'bury' → 'JURY'). Five of the paralexias were difficult to classify, but may be cases of letter misidentifications leading to visual paralexias. The remaining 77 were *visual* errors. Examples include 'canal' read as CANDLE, 'feather' read as FURTHER, 'music' read as MUSHY, 'slope' read as SLICK, 'victor' read as VISITOR. Only one of the 10 neologisms was a phonological regularization. This was the word 'halve' which was read as HALV. The appendix contains further details of all P.D.'s reading errors.

The visual errors that P.D. makes means it is extremely unlikely that he is using phonological strategies during reading. Since a sound-by-sound strategy might also lead to reading times that increase in line with the number of letters in a word (e.g. SAFFRAN [29]), the virtual absence of phonological regularizations in P.D.'s corpus of reading errors confirms that he should be classified as a letter-by-letter reader rather than as a surface dyslexic. The critical

question for WARRINGTON and SHALLICE's account of letter-by-letter reading is therefore whether or not the way in which P.D. reads is reflected in the way in which he spells.

Spelling

As a result of his hemiplegia, P.D. is forced to write with his left hand. This means that his writing is very slow and not particularly tidy (though the letters are clearly legible). However, his main spontaneous complaint is that, since his illness, he has forgotten how most words are spelt. We have confirmed this in formal written spelling tests conducted during several sessions over a 2-year period. In these tests, a word was read out and P.D. was asked to write it down. There was no time limit, and the word was repeated if this was requested. Out of 200 words that we have given him to spell in this way, P.D. was correct on only 63 (32%). Spelling was no better when he was asked to write down the names of 20 of the 40 common pictures (e.g. 'fork', 'arrow', 'cow', 'iron') from the PALPA battery. Only five of the names (25%) were spelt accurately, even though it was clear that he had the correct word in mind in 19 out of 20 cases. He named the remaining 20 pictures from this set without error.

We have classified the first 95 of his written spelling errors. Fourteen of these contained a missing letter or grapheme (e.g. 'pencil' was spelt PECIL, 'potato' was spelt POTTO, 'sister' was spelt SITER). Thirteen contained the wrong letter or grapheme (e.g. 'beard' was spelt BEARB, 'shoe' was spelt SHOW, 'tiger' was spelt TIKER). Only three could be described as errors of 'partial lexical knowledge' [10]. These were 'night' spelt NIHT, 'onion' spelt OUNYEN, and 'toe' spelt TOEW.

The overwhelming majority of P.D.'s spelling errors (65/95) are phonological errors or *regularizations*. Some examples are 'circle' spelt as SERKEL, 'elephant' spelt as ELAFUNT, 'member' spelt as MEMBA, 'photograph' spelt as FOTERGRAF, 'queen' spelt as CWEN, 'wallet' spelt as WHOLET, and 'water' spelt as WORTER. This is very similar to the pattern of spelling errors made by letter-by-letter reader T.P. [24], which are, as we noted earlier, characteristic of *surface dysgraphia* [14]. P.D. appears to have very little lexical knowledge available when attempting to spell words, and is forced to rely on fairly rudimentary sublexical phonology.

This was confirmed by a direct comparison of his ability to spell regular and irregular words. He was given 20 high-frequency regular words (e.g. 'cat', 'banana', 'potato', 'canal', 'swim') and 20 high-frequency irregular words (e.g. 'move', 'knock', 'ghost', 'photograph', 'sledge') from the PALPA battery spelling test. The words in this test are matched as closely as possible for imageability, number of letters and syllables, part of speech and morphemic complexity. P.D. spelt 12/20 regular words correctly, but only 2/20 irregular words ('egg' and 'move') were correct. A Fisher's Exact test showed that this difference was significant ($P=0.003$). A similar pattern emerged when he was asked to spell 48 words from a list devised by PARKIN *et al.* [23] in which the exception words are all *orthographically* regular and contained familiar letter sequences (e.g. 'front', 'pint', 'monk', 'have'). P.D. spelt 13/24 of the regular words correctly, but only 1/24 exception words ('have') was spelt correctly ($P=0.0005$).

Finally, P.D. shows a very similar pattern in *oral* spelling as in written spelling. Once more, he has great difficulty with irregular words and frequently produces phonological regularizations in place of the correct spelling (e.g. 'blood' was spelt B-L-U-D, and 'pretty' was spelt P-R-I-T-Y). When asked to spell orally the same set of 40 regular and exception words from the PALPA battery that he had spelt in writing 12 months previously, he was able to produce 7/20 correct spellings of regular words, but only 2/20 correct exception word

spellings (a difference that stops short of statistical significance ($\chi^2=2.3$; $P=0.12$). Examination of his oral spelling errors indicates that the majority are governed by a strong resemblance to the sound rather than the spelling of the target, and comparison of oral and written spelling errors in Table 2 shows a close parallel between the two types of response.

Since P.D. is poor at both written spelling and oral spelling, and since his spelling is impaired regardless of whether the input is from phonology or semantics, it appears most likely that P.D. has a lexical level spelling impairment.

Table 2. A comparison of oral and written spelling responses

Regular words	Oral	Written	Irregular words	Oral	Written
Cat	+	-	Aunt	antiy	annt
Banana	binna	banna	Acroplane	aryoplan	aroplan
Potato	pato	potto	Sword	swod	sorde
Canal	knal	kanl	Castle	caçal	cassole
Pet	+	-	Egg	+	+
Caravan	carovan	karvan	Elephant	elievent	clafant
Nest	+	+	Ghost	goste	goast
Robin	+	robbin	Giraffe	garaf	grath
Spring	sprik	-	Heart	hrat	hart
Bump	bumpc	+	Knock	+	nork
Jam	+	-	Lamb	lam	lame
Hold	+	+	Move	muve	-
Holiday	holieday	holeday	Photograph	footergraf	fotergraf
Bird	byd	+	Queen	kwene	cwen
Swim	+	-	Shoe	soow	show
Tent	tente	-	Sledge	slege	slcje
Sister	siter	siter	Soldier	solger	sogher
Tiger	tiga	tiker	Squirrel	sqirl	qiral
Wind	wine	-	Watch	woth	woche
Frog	frg	-	Yacht	yoht	vote

Comparison of reading and spelling errors

If WARRINGTON and SHALLICE'S [35] explanation of letter-by-letter reading is correct, then it should be the case that the way in which P.D. spells should be reflected in the way that he reads. In fact, though, P.D.'s reading and spelling are strikingly different. The first thing to note is the overall level of accuracy. P.D. was able to read approximately 70% of all the words that we gave him correctly. This figure is twice as high as the number of words that he is able to spell accurately (32%), despite the fact that the characteristics of the words are very similar - in many cases the sets of words are identical. It is difficult to see how the spelling system could be mediating accurate reading of words that P.D. cannot spell! In fact, P.D. is only able to spell accurately 38% of the words that he can read.

Most important of all, the phonological errors that he makes in spelling are very different from the visual errors that P.D. makes in reading. This difference in the pattern observed in reading and spelling occurs even when performance on the same lists of words is compared. The appendix provides details of the way in which P.D. reads words that he spells incorrectly. It can be seen that words which receive regularized spellings are sometimes read correctly (e.g. CONCEPT, MONEY), are sometimes read as visual errors ('body' > BABY, 'father' > FURTHER), and are sometimes given no response (e.g. 'theory', 'valour'). In short,

there seems little relationship between the way in which P.D. spells a word and the way in which he reads it. This means that it is extremely unlikely that his reading strategy involves the spelling system operating in reverse, contrary to the views of WARRINGTON and SHALLICE [35] and SHALLICE and MCCARTHY [31].

Reading regular and exception words

Further information about the possible use of phonological strategies in reading emerged from a comparison of P.D.'s ability to read regular and irregular words. Initially, he was given a list of 40 regular (e.g. 'take', 'free', 'market', 'effort', 'plant') and 40 exception words (e.g. 'come', 'sure', 'island', 'blood', 'colonel') from the PALPA battery. These words are matched for frequency, number of letters and syllables, number of morphemes, imageability, and part of speech. P.D. performed much better on the regular words (24/40) than on the exception words (10/40) ($\chi^2 = 8.65$; $P = 0.003$). This was somewhat surprising given the nature of his reading errors, which contained no regularizations. However, no attempt had been made to balance the regular and exception words for *orthographic* regularity in this list. Thus the exception words contained items such as *subtle*, *bouquet*, *yacht*, and *tsar*, which contain unusual letter combinations. It may well have been this rather than the fact that these words have exceptional grapheme/phoneme relations that made them relatively difficult for P.D. to read.

In order to test this explanation, P.D. was given PARKIN *et al.*'s [23] list of words to read in which the regular and exception words are controlled for orthographic regularity (e.g. 'front', 'pint', 'monk', 'have'). Under these circumstances, the regularity effect virtually disappears. He was correct on 17/24 of the regular words and 13/24 on the exception words—a difference that is no longer statistically significant ($\chi^2 = 8$; $P = 0.371$). It will be recalled from the previous section that when P.D. was given this list of words to *write* (6 months separated the two testing sessions), there was a statistically significant effect of regularity (13/24 vs 1/24).

There is an alternative explanation of why P.D. does not produce phonological regularizations during reading. There are reports [8, 17] of acquired dyslexics who use sublexical phonology in reading, but do not make phonological errors because of an editing strategy which stops them from uttering any response which they know (from consulting their speech lexicon) is not a genuine word. These authors showed that this was the case by giving their patients a mixed list of words and non-words to read. Under these circumstances, in which an editing strategy would be inappropriate, it was observed that they started to make a large number of regularization errors. We decided to investigate this possibility with P.D.

P.D. was asked to read a mixed list of 30 common words and 30 legal non-words from the PALPA battery. The words comprised 15 regular (e.g. 'need', 'same', 'fresh') and 15 exception words (e.g. 'give', 'broad', 'bind'). Since the exception words in this list are orthographically regular, this provides a further opportunity to look for a genuine regularity effect in P.D.'s reading. The non-words comprise 15 pseudohomophones (e.g. 'boal', 'jale', 'meen') and 15 non-homophonic non-words (e.g. 'fike', 'dath', 'noast') controlled for orthographic similarity, graphemic complexity, and number of letters and syllables. P.D. was given this list to read on two separate occasions, 1 year apart. Table 2 provides details of his errors on the regular and exception words on the two presentations. It can be seen that P.D. made no regularizations on the first administration of the test, and while he did make one regularization on the second administration, the overwhelming majority of errors are still visual paralexias. (By contrast, as many as 12 of the 14 irregular word errors that KATZ and

SEVUSH's [17] patient made under similar conditions were phonological regularizations.) In addition, the difference between the number correct for the two word-sets is very small, as it was with PARKIN *et al.*'s [23] lists. Finally, P.D.'s ability to read non-words (at least when mixed with real words) is poor. His overall success rate was only 47% regardless of whether the items were pseudohomophones or non-homophonic non-words.

Table 3. The way that P.D. read 15 regular and 15 exception words from the PALPA battery on two separate occasions. The list included 30 non-words

	Regular words		Exception words		
	Presentation 1	Presentation 2		Presentation 1	Presentation 2
Lend	leaned	lined	Broad	"prode"	"brode"
Clip	+	-	Womb	wham	"womble"
Same	+	+	Touch	torch	+
Like	+	+	Some	same	same
Shine	shin	"shane"	Bind	+	"drinned"
Steer	+	"shtee"	Bush	+	+
Fresh	+	+	Most	+	moss
Long	+	-	Both	dutch	+
Prune	+	-	Give	+	+
Need	+	+	Dove	+	+
Mist	-	+	Shove	+	shave
Dump	+	+	Bull	+	+
Pair	-	pain	Dread	+	+
Time	+	+	Have	+	+
Speed	+	+	Sieve	save	save
<i>Total</i>	13/15	11/15		9/15	8/15

It appears, then, that P.D. does not rely on phonological strategies when he reads.* His reading errors consist almost exclusively of visual paralexias rather than phonological regularizations. He performs in a similar way regardless of whether there are non-words in the list and, in this context at least, he is poor at non-word reading. One possible objection to our account is that P.D. does show a slight, though non-significant, difference between regular and exception words on both the PALPA and PARKIN *et al.* [23] lists. We would suggest, however, that the small but consistent difference between these word-types is an orthographic and not a phonological effect. Even though both sets take 'orthographic regularity' into account in their construction by using either bigram frequency [23] or N [24], there are a number of different measures of this variable (e.g. orthographic neighbourhoods and transitional trigram frequencies) that were not controlled for and may be exerting an effect. In support of this explanation, we would note that the size of the 'regularity' effect diminished significantly when orthographic regularity was taken into account and that P.D. produced visual rather than phonological errors in response to exception target words.

Since P.D.'s spelling, in contrast, relies almost exclusively on sublexical phonology, this means that he is unlikely to be using the spelling system in reverse to read, contrary to WARRINGTON and SHALLICE [35]. Instead, it seems that his reading is characterized by an

*We do not wish to claim that P.D. is unable to use sublexical phonology in reading aloud. Rather that he generally makes use of visual access to lexical information, even though this procedure is error prone and results in visual paralexias.

attempt to access the visual word-form system, consistent with the views of PATTERSON and KAY [24]. Since he continues to make visual errors even when he has correctly identified all the letters in a word, it seems likely that he is using a strategy of *approximate visual access* [7], which makes him produce a response that shares several letters with the word he is trying to read. Although P.D. may well use approximate visual access because of the length of time that it takes him to recognize letters in parallel [18], it is probable that the use of this strategy reflects a secondary impairment within the visual word-form system itself. In fact, the type of acquired dyslexia that this error-pattern most resembles is *visual dyslexia* [6, 21].

P.D.'s reading of his own mis-spellings

One of the reasons why PATTERSON and KAY [24] came to question the view that letter-by-letter reading involves the spelling system was their observation (p. 434) that the patient T.P. was sometimes quite unable to read her own mis-spellings. We investigated this issue with P.D. by asking him to perform a lexical decision task on his own mis-spellings, and on the correctly spelt version of the same word. We used a procedure that was broadly similar to that employed by CAMPBELL [5]. Twenty-six words were selected that P.D. had spelt *incorrectly* during a previous testing session, and each was presented to P.D. on an index card alongside the correct spelling of the same word. Examples of pairs of words used were FENCE/FENSE, GHOST/GOAST, SCHOOL/SCOOOL. A further 26 words were selected that P.D. had spelt *correctly* on a previous session, and these were paired with an experimenter-generated mis-spelling. Examples were DOGMA/DOGMER, HEAD/HED, MOVE/MOOVE. P.D. was told that only one of the two letter-strings on each card was a real word, and that he should go through the pack of cards putting a tick next to the one which he considered to be correct.

If P.D. is using the spelling system in reverse when he is reading, then he would be expected to select his own mis-spelling in preference to the real word. In fact, though, P.D. selected the correct word rather than his own mis-spelling on 20/26 occasions. This figure was very similar to the number of his own correct spellings that he selected when the alternative was an experimenter-generated mis-spelling (19/26). Once again, these results are not easy to reconcile with the account of WARRINGTON and SHALLICE [35], and suggest that very different processes are operating in P.D.'s reading and spelling. His rejection of his own mis-spellings shows that he has access to lexical information when he is reading that is not available to him when he is spelling.

P.D.'s recognition of orally-spelled words

In the final experiment, we examined P.D.'s ability to identify words that were read out to him letter-by-letter. The purpose was to discover the nature of the errors that P.D. would make on this task. Would he produce the sort of visual errors that occur when he is reading, or the phonological errors that characterize his spelling? There were two reasons for wanting to know the answer to this question. First, if P.D.'s performance in identifying orally spelled words resembles his reading, then this would be consistent with the idea that he *does* normally try to read words by identifying the names of the letters. Second, it would suggest, contrary to WARRINGTON and SHALLICE [35], that identifying orally spelled words makes use of the *visual word-form system* rather than the spelling lexicon.

P.D. was given 20 three-letter words and 20 five-letter words from HOWARD (pers. comm.) to identify from letter names. He correctly identified 16/20 of the three-letter words and 9/20 of the five-letter words (overall success rate = 63%). This compared with scores of 17/20 for

the three-letter words and 16/20 for the five-letter words (overall success rate = 83%) when he was asked to read the same set of words on a subsequent testing session.

Most important, P.D. produced exactly the same type of errors that he makes in reading (see Table 4). Examples of these visual paralexias include S-K-Y identified as 'ski', S-M-I-L-E identified as 'smell', T-R-O-U-T identified as 'throat', and W-H-A-L-E identified as 'wheel'. The only exceptions to this pattern were two words for which P.D. offered no response (A-N-K-L-E and H-O-N-E-Y), and two neologisms (P-I-A-N-O > 'pinoh', and J-E-W-F-L > 'gwill').

Table 4. P.D.'s ability to recognize words from their spoken letter names, compared with oral reading of the same words

3-letter words	Recognize	Read	5-letter words	Recognize	Read
Dog	+	+	Tower	+	+
Box	+	+	Salad	solid	solid
Cow	co	+	Smile	smell	!
Ant	+	+	Piano	"pin-oh"	-
Ear	+	+	Knife	-	+
Oar	are	"oh"	Spade	+	+
Rug	+	-	Tiger	+	+
Owl	+	+	Chair	+	-
Leg	+	+	Shirt	+	+
Pig	+	+	Ankle	"don't know"	-
Nun	+	-	Cider	-	"kidder"
Ape	+	+	Trout	throat	+
Ink	+	+	Grass	grace	+
Egg	+	+	Pearl	pale	-
Toe	+	+	Shark	+	shake
Cat	+	+	Whale	wheel	-
Sky	ski	ski	Honey	"don't know"	+
Ice	+	+	Jewel	"gwill"	-
Fly	+	+	Stone	+	stool
Gym	womb	+	Lunch	launch	-

On a subsequent testing session, in order to nullify any 'editing' strategy, P.D. was given a list of 20 irregular words such as WORD and ONE whose regularized pronunciations also form words [WARD, OWN). P.D. was correct on 8/20 (KNOW, COME, BOWL, WORD, TOUR, HEAD, SEW and BREAD). He made visual errors on 8/20 (F-R-A > 'ear', G-A-U-G-E > 'gone', G-R-E-A-T > 'grant', R-O-U-G-H > 'roach', H-E-I-R > 'here', O-N-E > 'on', C-O-U-C-H > 'coach', B-F-A-R > 'bird'). He made two responses which could be either visual errors or regularizations (S-H-O-E > 'show', W-H-E-R-E > 'weir'). He made no response on 2/20 (CEILING and HEIGHT). Even where an editing strategy would not prevent regularized pronunciations, then, P.D. still shows little sign of using phonological strategies on this task. Instead he typically responds with either the correct word or with a visually similar word.

These findings suggest that there are indeed striking parallels between the way in which P.D. reads words, and the way in which he identifies words from their spoken letter-names. This is consistent with the views of both PATTERSON and KAY [24] and WARRINGTON and SHALLICE [35] that letter-by-letter readers identify written words via serial letter identification. What Warrington and Shallice cannot explain, of course, is the striking difference between the visual errors that P.D. makes in identifying orally spelled words and

the phonological errors that he produces when attempting to spell words. The comparison between *identifying orally spelled words* and *oral spelling* is particularly striking. What this means is that P.D.'s identification of orally spelled words, like his reading, seems to involve the visual word-form system rather than the spelling system.

The recent literature provides two independent reasons for believing that it is best to associate the identification of orally spelled words with the reading system rather than the spelling system. The first is a priming study by MONSELL [22] that used normal readers as subjects. Monsell reports that the identification of orally spelled words facilitated subsequent recognition of these items on a *visual lexical decision task* relative to words that had not been presented earlier. Consequently, Monsell (p. 319) concluded that "letter-by-letter identification of words *does* activate the orthographic lexicon normally used for reading".

Secondly, KATZ [16] specifically investigated the recognition of orally spelled words in an acquired dyslexic, N.P., whose reading and spelling were both impaired. Like P.D., the type of errors that N.P. made in recognizing orally spelled words were much more similar to the type of errors that he made in reading than to the type of errors that he made in spelling (see p. 218 for examples). In addition, N.P. showed a similar overall level of accuracy in reading as in recognizing orally spelled words, whereas spelling was impaired more severely. There were also words that N.P. was able to spell correctly, but could not identify either from their orally presented letter names or during reading. Katz concluded (p. 216) that WARRINGTON and SHALLICE'S [35] account of the recognition of orally spelled words did not fit his results as well as PATTERSON and KAY'S [24] alternative.

What all this indicates is that the visual word-form system can accept input from serial sequences of letter names presented in either the visual or the auditory modality, as well as from sequences of letters picked up in parallel during visual perception. Consequently, we would suggest that P.D.'s main problems in reading come about for two distinct reasons. First, he has lost the ability to pick up letter information in parallel, and instead attempts to access the visual word-form system via serial letter identification. Second, there is probably an additional impairment at the level of the lexical representations themselves. This means that P.D. must frequently rely on a process of approximate access, and makes a number of visual errors as a consequence.

One issue that has not been resolved is the precise way in which the visual word form system might be accessed in either reading or the recognition of orally spelled words following serial identification of the word's letter names. One possibility is that the letter names might be converted into a visual image of the word which might then be fed into the visual word form system. We have several times asked P.D. for his own impression of how he reads. It is interesting to note that on one occasion he did come up with an account very similar to this. He said that he first tries to form a mental picture of all the letters which he then attempts to read as a word in his mind's eye. The problem that he apparently encounters when using this strategy is that he cannot 'see' all the letters simultaneously in his visual image. On all the other occasions that we have asked him, however, P.D. has been much more vague about the way that he reads and appears to be quite unclear about precisely what strategy he is attempting.

CONCLUSION

The primary aim of our case study of P.D. has been to evaluate two conflicting accounts of the compensatory strategies that are involved in letter-by-letter reading. In so doing, we have

come up with a variety of reasons why the explanation put forward by WARRINGTON and SHALLICE [35] and SHALLICE and MCCARTHY [31] cannot explain the reading strategies that this patient uses. Their hypothesis that letter-by-letter reading involves the use of the spelling system in reverse cannot account for the different type of errors that P.D. makes in reading and spelling, the absence of any strong correlation between words that he can spell and words that he can read, and the way in which he chose real words over his own incorrect spellings in lexical decision tasks.

On the other hand, the theory put forward by PATTERSON and KAY [24] provides a much more plausible account of the strategies that this patient seems to use during reading. Evidence has been presented which suggests that P.D., like normal subjects, reads words by accessing the visual word-form system rather than the spelling system. What makes P.D.'s reading so laborious is the fact he can no longer identify letters in parallel, and must access the visual word-form system by serial identification of letter forms. KAY and HANLEY [18] provide further discussion of the precise point at which the normal reading process has broken down in the case of P.D.

The findings that we have obtained with P.D. complement those that have recently been reported by RAPCSAK *et al.* [27] in their investigation of patient P.T. Like P.D., P.T. makes phonological errors in both written and oral spelling, but visual errors in reading. Furthermore, P.T. is a Type 1 letter-by-letter reader who has a severe letter recognition deficit, while P.D. is a type 2 letter-by-letter reader who has problems in word recognition even when he reports letters accurately. It therefore follows that the reverse spelling hypothesis is unable to provide an adequate account of either type of letter-by-letter reader.

Is there any way in which the reverse spelling hypothesis might be altered so as to accommodate the pattern of performance that P.T. and P.D. present? One possible argument might be that the poor spelling of these two patients comes about because of an inability to *access* representations in the spelling system for the purposes of *spelling*. It might then be claimed that lexical representations are nevertheless still stored in the spelling system and can be accessed for the purposes of letter-by-letter *reading*. In other words, P.D. and P.T. *do* have lexical representation available in the spelling system, but they can only access them whilst reading, not whilst spelling.

It is important to note that this new account would constitute a significant weakening of the hypothesis that letter-by-letter reading involves the spelling system. Perhaps the main reason for the popularity of WARRINGTON and SHALLICE's [35] and SHALLICE and MCCARTHY's [31] account relative to PATTERSON and KAY [24] is that it predicts the parallels that up until recently have been reported between the reading and spelling of individual letter-by-letter readers such as T.P. and K.C. [24]. An adherent of the new account might choose to argue that these links are purely coincidental and that, as a consequence, the cases of P.D. and P.T. (where the relationship breaks down) does not contradict the reverse-spelling hypothesis. Nevertheless, they would then have to acknowledge that cases such as T.P. and K.C. no longer provide any support for it. Under such circumstances, there would not seem to be any compelling reason to continue to advocate the spelling hypothesis.

Such a modification of the reverse spelling hypothesis faces a more fundamental problem, however. It will be noted that the argument is analogous to the one that ALLPORT and FUNNELL [1] made when they argued that dissociations between reading and spelling performance do not necessarily force the conclusion that separate lexicons are involved in reading and spelling. These dissociations might occur, they argue, because a single set of

lexical representations can be accessed for the purposes of reading but not for spelling (or vice-versa). Whatever the merits of this argument, it is clearly not one which could be advocated by a supporter of the reverse spelling hypothesis since the logic of the reverse spelling hypothesis demands that there are separate lexicons for reading and spelling. It would therefore be quite paradoxical if a supporter of the reverse spelling hypothesis were to use the same argument to claim that dissociations between reading and spelling performance in letter-by-letter reading reflect access impairments.

Finally, if the Warrington and Shallice account now seems less plausible than it did, so Patterson and Kay's theory seems rather more attractive today than in 1982. This is because of recent studies that have investigated the recognition of orally spelled words in normal subjects [22], and in an acquired dyslexic who is not a letter-by-letter reader [16]. These two studies have greatly increased our knowledge of what is involved in this task, and both come to a strikingly similar conclusion. This is that the identification of words from their letter names makes use of the reading system rather than the spelling system, consistent with the views of PATTERSON and KAY [24]. Furthermore, a specific model of how serial-letter identification might address the visual word-form system has been provided [16], whereas the idea that the spelling system can be accessed 'in reverse' [31, 35] still awaits detailed specification. We therefore believe that the theory put forward by PATTERSON and KAY [24] is now firmly established as the dominant account of the reading strategies that letter-by-letter readers employ.

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APPENDIX

(1) *A classification of P.D.'s oral reading responses*(a) *Visual paralexias.*

TARGET	RESPONSE	TARGET	RESPONSE	TARGET	RESPONSE
answer	insider	attitude	attained	audience	admittance
barge	bark	beard	board	beret	Bert
bridge	burglar	brief	brave	broad	board
brooch	brook	canal	candle	choir	cheer
circle	scissors	colonel	cooler	context	contest
cord	cod	cult	cute	curb	cub
engine	ending	fair	fire	father	further
feather	further	flannel	final	foot	fort
hobby	happy	indict	Indesit	infest	in first
kg	ledge	lend	leaned	music	mushy
night	neither	nurse	nuts	opium	open
peril	pearly	priest	pressed	scarce	shake
snoe	shove	shrewd	swede	sieve	slave/save
sait	shirt	sky	ski	slope	slick
smog	smoke	soldier	scissors	some	same
soot	set	stench	sense	sure	shirt
tomb	Tom	touch	torch	touch	took
tractor	presenter	tsar	teaser	uncle	uncivil
victor	visitor	wallet	weather	watch	water
weasel	whistle	wedding	wording	womb	wham
wrath	with	wrong	one	iron	around

(b) *Visual paralexia (but possible morphemic error).*

nerve	nervy	taste	taster	usual	unusual
-------	-------	-------	--------	-------	---------

(c) *Visual paralexia (but possible 'violation of final 'e' rule).*

dose	doss	duke	duck	hate	hat
lose	loss	shine	shin	smoke	smock
snake	snack				

(d) *Visual paralexia (but possible 'regularization').*

beard	bird	heart	hurt	sweat	swect
clown	clone				

(e) *Letter misidentification.*

boy	day	bread	dread	dread	bread
debt	bet	rib	rid	curb	curd
bump	pump	lamb	lamp	bury	jury
queen	gene	square	spare	gun	bun

(f) *Letter misidentification + visual paralexia.*

bat	dead	body	baby	bird	drink
both	dutch	break	drink		

(g) *Possible semantic error.*

bridge	path
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(h) *Neologisms.*

ape	/æpə/	bat	/bət/	castle	/ɛʃæstl/
knock	/nɒk/	pot	/bɒt/	seep	/sɜp/
sword	/swɒd/	tongue	/tʌŋgi/	yacht	/jæktɪd/
halve	/hælv/				

(2) *A classification of P.D.'s written spelling responses*(a) *Regularizations (phonic spellings).*

TARGET	RESPONSE	READ AS
body	bodey	baby
bread	bred	dread
castle	cassole	chastle
child	childd	+
circle	serkel	scissors
clown	clowen	clone
clue	klow	+
concept	consept	+
effort	efut	+
elephant	elafunt	+
elbow	ellbow	+
fact	facket	"don't know"
father	farther	further
fence	fense	+
fire	fihe	"don't know"
ghost	goast	+
gravy	gravi	+
heart	hart	hurt
holiday	holeday	+
kitten	kiten	+
letter	leter	+
member	memba	+
money	muncy	+
pact	packt	"don't know"
photograph	fotergraf	+
pillow	pilo	+
plea	pley	+
potato	pottatow	+
pupil	piupel	+
queen	cwen	gene
radio	radeo	+
road	rode	+
robin	robbin	+
rib	ribb	rid
school	scool	+
session	sesyon	"don't know"
sledge	slejc	+
sword	sord	"swodd"
system	sistem	+
theory	thercy	"don't know"
valour	vala	"don't know"
wallet	wholet	weather
water	worter	+
weed	wcad	+

(b) *Regularizations associated with final 'e'.*

heel	hele	+
hotel	howtele	+
lamb	lame	lamp
lunch	lunche	+
pill	pile	+
plum	plume	+

TARGET	RESPONSE	READ AS
skull	sculle	+
seat	setc	+
realm	relme	+
sword	sorde	+
watch	woche	+
wig	wige	+
acropplane	acropplan	+
engine	engin	ending
kettle	ketel	-
marriage	marag	"don't know"
plane	plan	"don't know"
snake	snach	snack
village	villag	-
woe	wow	"don't know"
battle	battl	"don't know"

(c) *Missing letter.*

aunt	annt
banana	banna
canal	kanl
caravan	karvan
church	cerg
pencil	pcil
picture	pickr
potato	potto
principle	prinapul
sister	siter
sky	sy
squirrel	quiral
tongue	tune
character	karitor

(d) *Wrong grapheme.*

beard	bearb
cow	caw
doctor	dorektor
episode	epesold
mother	mucer
shoe	show
square	sqer
surf	serve
tea	tye
tiger	tiker
uncle	huncel
yacht	vote
knock	nork

(e) *Partial lexical knowledge.*

night	niht
onion	ounyen
toe	toew