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A Characterisation of the Word Superiority Effect in a Case of Letter-by-letter Surface Alexia

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An important characteristic of the word superiority effect (WSE) observed in normal subjects is that it extends to words displayed in mixed-case letters, e.g. fAdE is better identified than gAdE (McClelland, 1976). Because upper- and lower-case letters are treated as functionally equivalent within the orthographic system (e.g. "A"/"a" map onto abstract letter identities; Coltheart, 1981), it is often argued that orthographic codes mediate the WSE. In the present paper, we report an intact WSE in a letter-by-letter surface alexic (IH) when words and "word-like" pseudowords were displayed quickly and then masked. Consistent with the claim that orthographic codes mediated these effects, the WSE extended to words typed in mixed-case letters, and IH failed to show a WSE for the same class of words for which he has impaired orthographic knowledge; namely, low-frequency words. Based on these results, we argue that IH gains better access to orthographic knowledge than current theories of letter-by-letter reading would predict.

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INTRODUCTION

Dyslexic patients are classified as letter-by-letter readers whenever they exhibit an abnormally large increase in reading reaction times as word length increases. The effect of word length on reading times varies greatly from one case to another, but a typical patient might require three or four seconds to read three-letter words, and reading times often increase by two–three seconds—or more—for every additional letter. In some cases, the reading deficit occurs in the absence of impaired language and, more dramatically, without impaired writing or spelling. However, letter-by-letter reading is often accompanied by additional language problems, most commonly surface dyslexia and surface dysgraphia.

Three general accounts of letter-by-letter reading can be delineated. In one view, letter-by-letter reading is the result of a perceptual deficit that prevents patients from constructing accurate shape descriptions of stimuli whenever multiple forms must be processed rapidly or in parallel; that is, patients suffer from simultagnosia (e.g. Farah & Wallace, 1991; Kinsbourne & Warrington, 1962; Levine & Calvanio, 1978). By this account, the uptake of all forms of visual information is impeded, but the deficit is manifested most clearly in reading because the identification of words is particularly dependent upon the parallel analysis of multiple shapes (letters) (for a related view, see Patterson & Kay, 1982). In order to compensate for this perceptual impairment, patients are assumed to analyse the visual structure of words one letter at a time, leading to their slow naming latencies. According to a second view, letter-by-letter reading reflects a difficulty in *identifying* letters, rather than constructing a visual description of letters (e.g. Arguin & Bub, 1993; see also Reuter-Lorenz & Brunn, 1990; Kay & Hanley, 1991). These authors note that one of the first stages of reading requires a mapping of shape information to abstract letter identities (e.g. Coltheart, 1981) and, by this account, a disruption to the mapping function leads to letter-by-letter reading. In a third view, letter-by-letter reading reflects damage to central mechanisms of reading that are responsible for parsing letter strings into familiar letter units—the so-called word form system (e.g. Warrington & Shallice, 1980). In order to read in the absence of this system, patients are thought to rely on compensatory strategies that require the laborious identification of each separate letter in a word.

Of course, there is no a priori reason to assume that the same functional impairment is responsible for all cases of letter-by-letter reading (cf. Price & Humphreys, 1992); indeed, all of these theories may characterise particular subsets of patients correctly. What we would like to emphasise, however, is that all of these accounts share the assumption that the critical impairment (whatever it might be) prevents patients from gaining normal access to lexical–orthographic representations from print, and this in turn leads to their slow reading. Accordingly, we will introduce the descriptive term *orthographic-access* view to characterise this general approach. Another possible account that is rarely considered, however, is that a subset of patients gain relatively normal access to lexical–orthographic representations (i.e. localist representations of words, such as logogens; cf. Morton, 1979), and that for these patients, the deficit occurs at a later stage in the reading process—perhaps in the mapping procedure between orthographic and phonological knowledge. We adopt the term *post-access* view to characterise that group of patients who are presumed to contact orthographic codes relatively efficiently, and who nevertheless read in a letter-by-letter fashion.

Despite the widespread acceptance of the orthographic-access view, two sets of results suggest that a subset of letter-by-letter readers gain better access to orthographic knowledge than this approach might lead one to expect. First, some patients access orthographic representations surprisingly well when reading is tested *covertly*. For example, patients have been reported who carry out lexical decisions (word/pseudoword discriminations) and semantic classifications of words (e.g. living/nonliving) at exposure durations too brief for them to identify the target items explicitly (e.g. Shallice & Saffran, 1986; Coslett & Saffran, 1989; Coslett, Saffran, Greenbaum, & Schwartz, 1993). Similarly, Bub and Arguin (1995) reported that a pure alexic patient (DM) was able to distinguish between high-frequency words and "word-like" pseudowords in a lexical decision task when reaction times were measured, and his responses were relatively quick (approximately 800msec) and insensitive to word length. More interestingly, DM continued to make fast lexical decisions when items were presented in mixed-case letters (e.g. tAbLe vs. jAbLe). Since upper- and lower-case letters are treated as functionally equivalent within the orthographic system (e.g. Besner, Coltheart, & Davelaar, 1984; Coltheart, 1981; McClelland, 1976), this latter finding provides rather direct evidence that orthographic codes mediated his performance. Taken together, these covert reading results pose somewhat of a challenge to orthographic-access theories, because it might have been expected that abnormally long reading times would always accompany long lexical decisions and long semantic categorisations—performance on all of these tasks requires access to orthographic codes.

Second, reports of an intact word superiority effect (WSE) in some letter-by-letter readers (e.g. Bub, Black, & Howell, 1989; Reuter-Lorenz & Brunn, 1990) are difficult to reconcile with the claim that all patients have difficulties in accessing lexical–orthographic representations. The patient WL, for example, was better able to identify briefly exposed words compared to briefly exposed pseudowords (e.g. BLAP), or nonwords (e.g. IXJC; Reuter-Lorenz & Brunn, 1990). In fact, the WSE obtained for WL was equal in magnitude to that obtained with a control subject. This finding is important because, in normal subjects, the advantage of words over pseudowords is thought to depend upon words gaining specific access to appropriate lexical–orthographic representations following the parallel encoding of letters, whereas pseudowords only access sublexical codes and word neighbours (cf. Adams, 1979; McClelland & Rumelhart, 1981). To take a concrete example, the word HAND is assumed to gain specific access to an orthographic code of HAND whereas the pseudoword HANE accesses related lexical and sublexical orthographic codes such as HAND, HATE, LANE, AND, HAN, HA, etc. Selective access in the former case is assumed to facilitate the identification of HAND relative to the non-selective access occurring with HANE; thus a WSE is obtained. Note, if this is the correct characterisation of the WSE, then the WSE should be reduced under conditions in which words cannot gain specific access to lexical–orthographic representations following the parallel encoding of letters. Accordingly, the finding that WL showed a normal size WSE suggests that he gained specific access to orthographic word codes following brief presentations of words.

In order to accommodate these results with orthographic-access accounts of letter-by-letter reading, there have been two general proposals. According to the first, these preserved reading skills reflect suboptimal activation of orthographic and semantic representations that normally mediate reading. For example, exposure to a word is assumed to produce sufficient orthographic activation to mediate lexical decisions—at least for high-frequency words—but not enough activation to identify words explicitly (e.g. Arguin & Bub, 1993; Bub & Arguin, 1995; Howard, 1991; Shallice & Saffran, 1986). Similarly, it has been suggested that this suboptimal activation might be sufficient to mediate a WSE in some patients—at least when the identification of words is compared to random letter strings—but again, this degraded access is assumed insufficient for fast naming (e.g. Bub et al., 1989). Applying the same logic, the preserved semantic categorisation of some letter-by-letter readers may reflect partial access to semantic information, but this access is presumed inadequate to support normal reading. Note, the key assumption of this approach is that the preserved reading skills of letter-by-letter readers reflect the preserved functions of the orthographic and semantic systems that normally subserve reading.

According to the second approach, covert reading and the WSE depend upon processing mechanisms that are functionally and anatomically separate from those that normally mediate reading. Perhaps the chief proponents of this approach are Coslett and his colleagues (Coslett & Saffran, 1989; Coslett et al., 1993), who attribute covert reading to the limited language competence of the right hemisphere. In support of this position, Coslett et al. (1993) reported two similarities between the covert reading of a pure alexic patient (JWC) and the reading skills of the right hemisphere, as demonstrated by studies of commissurotomy and hemispherectomy patients; namely, JWC was better at making lexical decisions to high- compared to low-imageability words, as well as to nouns compared to functors matched in terms of frequency and imageability. This same pattern of reading is found in the right hemisphere (Patterson, Varga-Khadem, & Polkey, 1989). Similarly, Reuter-Lorenz and Baynes (1991) found that the reading competence of the right hemisphere parallels the reading skills of pure alexic patients in a number of respects, including that the right hemisphere supports a WSE. This finding is important, because it is commonly assumed that the WSE reflects access to the representations that mediate normal reading—i.e. orthographic codes within the left hemisphere. But given the Reuter-Lorenz and Baynes finding, the right-hemisphere hypothesis must be considered. Indeed, Reuter-Lorenz and Baynes endorse the view that the right hemisphere mediates the WSE in letter-by-letter readers.

To the extent that covert reading skills and the WSE can be attributed to suboptimal access to lexical–orthographic representations or, alternatively, to perceptual representations outside the reading system altogether, then the results do not compromise orthographic-access theories of letter-by-letter reading. On either account, it can be assumed that letter-by-letter reading is the product of poor access to orthographic knowledge, and that the preserved reading skills reflect capacities left unaffected by the impairment. An alternative interpretation of these findings, however, is that some of the preserved reading skills reflect relatively normal access to orthographic codes and, in these cases, the slow reading reflects a deficit in the reading process after orthographic access, i.e. the post-access view.

The experiments reported later provide an initial attempt to adjudicate between these two positions by providing a careful characterisation of the WSE in a letter-by-letter reader. In designing the experiments, we took care to minimise the likelihood that any WSE was mediated by suboptimal access to lexical–orthographic codes or was the product of non-orthographic knowledge. In order to address the first issue, we assessed the WSE by comparing the identification rates of words to "word-like" pseudowords matched in terms of bigram frequency and neighbourhood density (neighbourhood density refers to the number of words than can be constructed from the item by changing one letter; Coltheart, Davelaar, Jonasson, & Besner, 1977). Given that the items were matched on these variables, we would argue that the critical orthographic distinction between these items is that words are represented as lexical–orthographic codes whereas the pseudowords are represented sublexically. Therefore, an identification advantage for words over pseudowords would suggest that words continue to gain selective access to lexical–orthographic representations. Furthermore, in order to ensure that any obtained WSE reflects the parallel encoding of letters in words rather than a sequential analysis of letters, we assessed the WSE when items were presented very briefly and a post-stimulus mask was included.

In order to address the concern that a WSE could be mediated by reading mechanisms within the right hemisphere, we included a condition in which words and pseudowords were displayed in mixed-case letters (e.g. CaMe vs. HaNe). There is a variety of evidence that upper- and lower-case letters are treated as functionally equivalent within the orthographic system located in the left hemisphere (e.g. A/a access the same abstract letter code; Besner et al., 1984; Coltheart, 1981; Evett & Humphreys, 1981), and thus a mixed-case WSE would support the view that normal reading mechanisms mediated the WSE. Interestingly, there is also some preliminary evidence that the perceptual codes of letters and words within the right hemisphere are represented in a case-specific manner. That is, the letters A/a may be represented separately within a perceptual system in the right hemisphere. One form of evidence in support of this latter claim was reported by Reuter-Lorez and Baynes (1991), who assessed priming for single letters in the left and right hemisphere of a callosotomised patient (JW). The patient was presented with a series of target letters in upper case, and he was asked to name the targets as quickly as possible. Targets were preceded by primes in lower case, half of which shared the same name (e.g. prime= h, target= H), and half of which did not (e.g. prime= t, target= H). The critical finding was that the target was named faster in the former condition as long as items were presented to JW's right visual field (left hemisphere). No facilitation was obtained when items were presented to his left visual field (right hemisphere). Based on this result, the authors concluded that the left, but not the right, hemisphere represents letters in an abstract orthographic format[1] (for additional evidence that the left and right hemispheres code letters and words in abstract and specific formats, respectively, see Geffen, Bradshaw, & Nettleton, 1972; Marsolek, Kosslyn, & Squire, 1992). If this analysis is correct, then the finding that a WSE extends to case-alternated words would strongly support the view that orthographic representations within the left hemisphere mediate the WSE.

[1]It is interesting to note that JW is the same patient who showed a robust WSE in his right hemisphere, leading these authors to argue that the right hemisphere in letter-by-letter readers mediates the WSE.

More generally, there is a need to provide a systematic study of the WSE in a letter-by-letter reader, given the mixed set of results that have been reported to date. When a WSE has been obtained, words were better identified than pseudowords in some cases (Reuter-Lorenz & Brunn, 1990), whereas in other cases, words were better identified than random letter strings, but no difference was obtained between words and pseudowords (e.g. Bub et al., 1989). In still other cases, no WSE was obtained at all (e.g. Behrmann, Black, & Bub, 1990; Kay & Hanley, 1991). Of course, these different results may reflect differences between patients, but it should also be noted that different procedures and materials have often been used to assess the WSE in the various studies, and these experimental differences may also account for some of the inconsistencies. In order to compare our results with previous studies, we assessed the WSE using two procedures that have frequently been employed in testing other patients. A careful assessment of guessing was also included, in order to ensure that our findings reflect orthographic processes rather than something else.

CASE HISTORY

IH was a 45-year-old right-handed male at the time he suffered from a subarachnoid haemorrhage that was drained surgically in September 1983. No CT scan is available to us; however, the neurological case report indicates that IH suffered a left temporal-occipital haematoma. Following the haemorrhage, IH's main behaviour complaints were of a complete right-homonymous hemianopia, anomia, surface agraphia, and reading problems. A WAIS indicated an IQ in the low normal range (90) with no asymmetry between the verbal (89) and performance (92) scales. IH's anomia was verified with the Boston Naming test, on which he obtained a score of 6/60. Testing was discontinued on trial 19 after 6 consecutive errors. In that test, the patient made many circumlocutions and mentioned words semantically related to the target (he realised these answers were incorrect), indicating that he recognised the stimuli. Nevertheless, he often failed to find the appropriate name even with substantial phonemic cueing. In order to document IH's dysgraphia, we asked him to spell a set of 144 words with ambiguous spellings that were read aloud to him along with a context to specify the word we had in mind. IH correctly spelled 26/144 on his first attempt, and 6 additional items on a second try. In all cases, his spellings were phonologically plausible, for example, spelling DIRT *d-u-r-t*, and hazy *h-a-z-e*. With one exception noted later, the present set of experiments were performed with IH between June 1993 and December 1993.

EXPERIMENTAL TESTS

The Effect of Word Length and Word Frequency on Reading

In order to document IH's reading deficit, we presented him with a list of 160 words one at a time on a Macintosh computer using Psychlab experimental software (Bub & Gum, 1988). The list included an equal number of 4-, 5-, 6-, and 7-letter items, and for each word length, 20 words were high frequency (greater than 100 occurrences per million), and 20 were low frequency (less than 10 occurrences per million). Items were presented in a random order, and were displayed in upper-case 24-point Geneva bold font. During the reading task, IH was asked to name each word as quickly as possible, and his reaction times were measured by a voice trigger. Targets were displayed until a response was made, at which time it was replaced by a blank white field. In order to increase the number of observations per condition, IH was asked to read the same list after a one-week delay. As can be seen in Fig. 1, IH's reading times were long and increased by approximately 500msec for each additional letter, a pattern indicative of letter-by-letter reading. An ANOVA performed on IH's results using individual trials (in this case, correct reading responses) as independent samples confirmed that latencies to read words increased with number of letters, $F(3, 194) = 18.2$, $MSe = 796{,}477$, $P < 0.001$. It is interesting to note that IH was somewhat faster in naming words a second time when the list was repeated (overall mean RT = 2697msec) compared to naming words the first time (overall mean RT = 3137msec), which

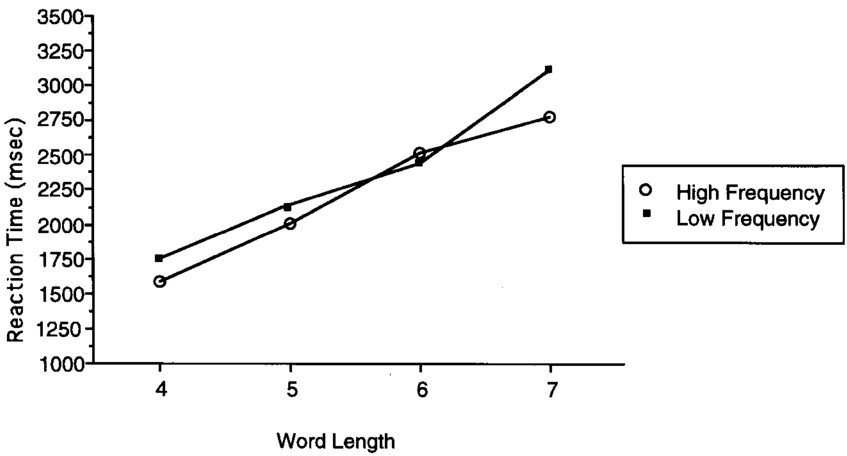

FIG. 1. IH's reading latencies for high- and low-frequency words as a function of word length.

presumably reflects priming from one session to the other. Nevertheless, a similar increase in reading times as a function of word length was obtained on both occasions. IH was also 140msec faster to name high-frequency (2217msec) compared to low-frequency (2357msec) words, but given the variability of his naming times this effect did not approach significance, $F(1, 194) = 1.17$, $P > 0.1$. However, evidence that frequency influences reading was obtained when IH was asked to read a set of 1229 4-letter words that varied in frequency from 1–1000[2]. A simple regression revealed an effect of frequency on his latency to read words correctly, $F(1, 1074) = 5.8$, $MSe = 105{,}834$, $P < 0.05$.

As can be seen in Table 1, IH also made many reading errors while completing the above task, especially when reading long words[3]. His error rate in reading high- and low-frequency words were similar at each length, apart for 5-letter words, where he made significantly more errors with low- (0.43) compared to high- (0.09) frequency words, $\chi^2 = 10.77$, $P < 0.01$. As is common in letter-by-letter reading, his errors were predominantly visual in nature (e.g. Patterson & Kay, 1982). For example, IH read SUSPEND as SUSPECT and THEORY as THERE. However, a number of his errors were also phonological regularisations, such as pronouncing TIGER with a short "i" sound, as in "fig," an error indicative of surface dyslexia. The co-occurrence of letter-by-letter reading with surface dyslexia has been reported in a number of cases (e.g. Friedman & Hadley, 1992; Kay & Hanley, 1991; Patterson & Kay, 1982) and, accordingly, we thought it important to characterise the extent of his surface dyslexia.

TABLE 1
Proportion of Reading Errors as a Function of Word Length and Word Frequency

Word Length	*High Freq.*	*Low Freq.*
4-Letter Words	0.08	0.08
5-Letter Words	0.09	0.43
6-Letter Words	0.38	0.53
7-Letter Words	0.43	0.53

[2]This experiment was carried out in 1992, whereas all other experiments were carried out in the Fall semster of 1993.

[3]It should be noted that we considered a reading trial as an error when IH pronounced the first phoneme of the word correctly, and then paused. This of course set off the voice trigger, making the reaction time to this item meaningless. Accordingly, the error rates listed in Table 1 provide an upper bound to his reading errors, which includes trials in which he only named the first phoneme (correctly) and trials in which he misread the word. However, these errors due to pausing only occurred on approximately 5% of the trials.

The Effect of Spelling–Sound Regularity on Reading Accuracy

In order to assess IH's surface dyslexia, we selected a set of 105 regular and 105 irregular words from Behrmann and Bub (1992). Words were between 4 and 6 letters in length, and were selected from 3 frequency ranges: below 20, 20–99, and above 100. Within each frequency range, regular and irregular words were matched on length. A number of words in the Behrmann and Bub (1992) study were classified as very irregular on the Shallice, Warrington, and McCarthy (1983) scheme, and we included an equal number of these items (10) within each frequency range.

Words were displayed in random order in lower-case 24-point Geneva font, and IH was instructed to read each word as quickly and accurately as possible. Items were displayed on the computer screen until a voice trigger was set off by IH's response. Figure 2 displays IH's accuracy in reading regular and irregular words as a function of frequency. Clearly, IH had the greatest difficulty naming irregular words, and his difficulty was particularly severe for low-frequency irregular words. By contrast, his naming accuracy for regular words was unaffected by the frequency manipulation. A series of chi-square tests confirmed this description of the results: IH was equally accurate at naming high- and low-frequency regular words ($\chi^2 = 0.85$, $P > 0.1$), but he made significantly more errors naming low-frequency irregular words compared to high-frequency irregular words ($\chi^2 = 11.2$, $P < 0.05$). In addition, IH correctly named low-frequency regular words more often than low-frequency irregular words ($\chi^2 = 16.56$, $P < 0.01$), but this difference did not approach significance for higher-frequency items (for similar results, see Behrmann

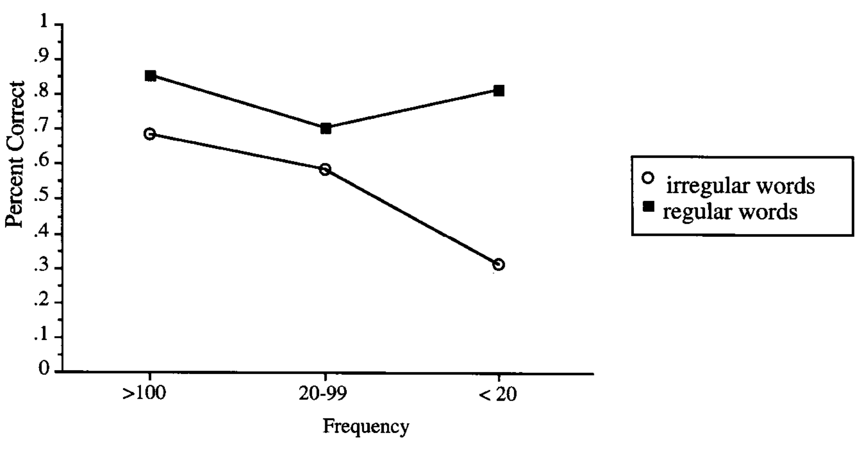

FIG. 2. IH's accuracy in reading regular and irregular words as a function of word frequency.

& Bub, 1992; Patterson & Hodges, 1992). As one might expect, IH's errors with irregular words tended to be "regularisations." Based on IH's overall pattern of reading, it apears that he suffers from a combination of pure alexia and surface dyslexia, so-called *letter-by-letter surface alexia* (Friedman & Hadley, 1992), or type II letter-by-letter reading (Patterson & Kay, 1982).

Locus of the WSE

As noted earlier, we hoped to gain some insights into the mechanisms that mediate the WSE in a letter-by-letter reader by comparing the WSE when words and matched pseudowords are displayed in upper- and mixed-case letters. To the extent that the WSE is mediated by abstract orthographic representations, the effect should be robust in both conditions.

An Assessment of the WSE with Upper-case Words and Pseudowords

The WSE can be obtained under a variety of experiential conditions, and each of these conditions has distinct advantages and disadvantages. In the most common procedure, words and pseudowords (BLAP) are displayed briefly on the computer screen, with each item followed by a pattern mask. Subjects are then presented with two letters in a given position, and they are asked to select the letter that was exposed. For example, if the word "FACE" was presented, subjects might be presented with the alternatives __E or __T, with the correct response being __E. In the case of word targets, both alternatives furnish equally plausible completions of the remaining context—in this example, FAC-E and FAC-T, respectively. The WSE is obtained when subjects are better able to select letters embedded in words compared to pseudowords. In a variant of this procedure, two alternative words or pseudowords are displayed, and the subject must select between the items; FACE and FACT in this example (McClelland & Johnston, 1977).

The advantage of the forced-choice procedure is that it minimises the effects of guessing on performance because a subject cannot select the proper letter based on an identification of the context letters. For example, a subject who identifies the letters "FAC-" when FACE was presented quickly cannot make an informed guess regarding the final letter, because both __E and __T are plausible completions of the context FAC__. Accordingly, any WSE obtained using this procedure must reflect the improved processing of the *target* letter rather than the product of an informed guess based on the identification of the context letters. The problematic feature of the forced-choice task, however, is that the level of accuracy by chance alone is 50%, and accordingly, the range of performance is restricted, rendering the task an insensitive measure of the WSE. Indeed, the advantage of identifying letters in the context of words compared to pseudowords is generally quite small in studies that have employed this procedure with normal subjects, and a number of studies have failed to obtain a significant effect (e.g. Manelis, 1974; Juola, Leavit, & Choe, 1974; McClelland & Johnston, 1977).

A procedure that provides a more sensitive measure of the WSE is the free-report technique. In this task, words and pseudowords are presented briefly, followed by a pattern mask, and a WSE is obtained when subjects are better able to identity all of the letters in words compared to pseudowords. A critical feature of this task is that the level of accuracy by chance alone is substantially less than 50% given the partial identification of a target. For exmaple, the letters FAC_ of FACT do not greatly constrain the identity of the letter in the fourth position. Given the greater range of performance in this task compared to the forced-choice task, it should be easier to measure a WSE. In fact, a number of studies have demonstrated substantial advantages for words relative to pseudowords employing this technique in normal subjects, ranging from a difference of 20% (McClelland & Johnston, 1977) to as much as 50% or greater (Adams, 1979). The problem with this task, however, is that performance, at least in principle, can be contaminated by post-perceptual guessing strategies. That is, subjects might use their knowledge of words in order make informed guesses regarding the identity of quickly displayed words. But nevertheless, evidence has accumulated that this factor plays a negligible role if certain precautions are taken. For example, including a post-display mask that limits the time available to formulate a reasonable guess based on partial visual cues, and including instructions to report targets letter-by-letter, reduce the effects of guessing (McClelland & Johnston, 1977). In fact, the role of guessing on the forced-choice and free-report tasks was directly assessed by Johnston (1978), and no evidence of guessing was obtained (also see Estes, 1975).

A clear demonstration that the free-report task is a more sensitive measure of the WSE than the forced-choice task was reported by McClelland and Johnston (1977), who employed both tasks within the same study: identification of words (0.39) was significantly better than pseudowords (0.19) in the free-report task, whereas identification of words (0.81) and pseudowords (0.79) did not differ in the forced-choice task. Critically, guessing was ruled out in both tasks. Given the performance of normal subjects, it is not surprising that a word/pseudoword difference has not been reported when letter-by-letter readers were tested with the forced-choice task (Bub et al., 1989). In the present experiment, we adopted a procedure similar to that of McClelland and Johnston (1977) and assessed the WSE with both tasks. Of course, the most striking demonstration of a WSE would be a robust effect in each task, but given the results with normal subjects, a more likely outcome is that a WSE will be restricted to the free-report task. Whenever possible, we have adopted experimental procedures that were intended to minimise guessing on the free-report task, and we have included checks in order to assess the role of guessing.

Materials and Procedure. A set of 220 4-letter words was selected such that an equal number of words were in the following frequency ranges: $>$200, 75–200, 25–74, 10–24, $<$10 (Francis & Kučera, 1982). Each word was matched with an orthographic neighbour that differed by a single letter in either the third or fourth position, and that fell within the same frequency range. For example, CAME and CASE were both included in the frequency range above 200. A set of 220 pseudowords was matched as closely as possible with the words. Half of the pseudowords were matched with one member of each word-pair in terms of cumulative bigram frequency and number of orthographic neighbours. For example, the nonword HANE was matched with CAME, because they are both similar in summed bigram frequency (348 vs. 386, respectively; Mayzner & Tresselt, 1965) and neighbourhood density (16 vs. 17, respectively). For each of these pseudowords, a second pseudoword was constructed by changing the third or fourth letter of the item, creating a pseudoword pair; for example, HANE/HABE. Accordingly, only half of the pseudowords were directly matched with words. Nevertheless, the average summed bigram frequency of all words (184) and all pseudowords (165) was quite similar, as was the number of orthographic neighbours for words (7.69) and pseudowords (6.38). During the course of the experiment, both members of the word and pseudoword pairs were tested as target.

Word and pseudoword targets were presented by means of a Macintosh Plus computer in upper-case letters, black 24-point Geneva font on a white background. At the beginning of each trial, a central fixation point appeared for 1000msec, and following a 500msec ISI, the target was presented. Targets were exposed tachistoscopically for 83msec in IH's intact visual field (the final letter of the target item occurred slightly to the left of the central fixation point), and an overlaid set of Xs and Os displayed for 50msec served as a post-mask (ISI of mask-target = 0msec). Then, IH completed the free-report task: A question mark (?) was displayed 500msec after the offset of the mask, and IH was asked to name the 4 letters that were presented on the screen. The task of naming individual letters rather than complete items was selected because these instructions are thought to reduce the influence of guessing (cf. McClelland & Rumelhart, 1981). Finally, IH completed the forced-choice task. The target and its neighbour were presented one above the other, and IH was asked to select the item that had been exposed. For example, if the word HAND was presented on the computer screen, both HAND and HARD were included in the forced-choice task. The correct item was located above the distractor on half the trials, and below on half of the trials. We included a choice of two words, rather than single letters, because this version of the forced-choice task has been used to assess the WSE in letter-by-letter readers in the past (Bub et al., 1989; Behrmann et al., 1990).

The target duration of 83msec was selected because a pilot experiment revealed that IH could identify approximately 0.30 of high-frequency words displayed under free-report conditions (these words were not included in the present experiments). Although this accuracy rate is sub-optimal for showing a WSE—accuracy rates of approximately 50% are considered optimal (McClelland, 1976)—short exposure durations are also thought to minimise the influence of guessing on the free-report task (McClelland & Rumelhart, 1981). In a final attempt to reduce guessing, words and pseudowords were randomly intermixed, and they were presented in blocks of 44 trials. IH completed a series of blocks, once a week, over several weeks.

Results and Discussion.

1. Forced-choice Task. Table 2 displays the proportion of words and matched pseudowords correctly identified in the various experimental conditions. As can be seen in this table, IH identified a similar number of words and pseudowords; collapsing across frequency, the proportion of items identified was 0.69 and 0.75, respectively, which is not a significant

TABLE 2
Proportion of Words and Matched Pseudowords Displayed in Upper-case Letters Identified on the Forced-choice Task as a Function of Word Frequency

Word Frequency	*Words*	*Pseudowords*
> 200	34/44	33/44
75–200	32/44	28/43
25–74	26/44	33/44
10–24	31/44	33/44
1–9	29/44	39/44

difference ($\chi^2 = 2.47$, $P > 0.1$)[4]. Furthermore, a set of contrasts comparing word and pseudoword identification rates at each frequency range revealed only one significant effect, with the lowest frequency words being *less* often identified than matched pseudowords, ($\chi^2 = 6.47$, $P < 0.05$). We have no explanation as to why pseudowords were better identified than matched low-frequency words, and can only assume this difference was a product of chance. In fact, this difference does not achieve significance when the alpha rate for this unplanned contrast is adjusted according to the Bonferroni procedure in order to correct for the inflated type I error rate associated with multiple contrasts (alpha/6 = 0.008). So clearly, there is no evidence for a WSE based on the forced-choice results[5].

2. *Free-report Task.* The proportions of correctly identified words and matched pseudowords in the various conditions are displayed in Table 3. The criterion for correct identification was that all four letters were named in the correct order. Collapsing across frequency, IH was better able to identify words (0.25) compared to pseudowords (0.13), revealing an overall WSE ($\chi^2 = 9.15$, $P < 0.01$). Furthermore, a set of individual contrasts comparing word and matched pseudoword identification rates at each word frequency range indicated that the WSE was greater for high- compared to low-frequency words: The highest frequency words (frequency > 200) were better identified than matched pseudowords,

TABLE 3
Proportion of Words and Matched Pseudowords Displayed in Upper-case Letters Identified on the Free-report Task as a Function of Word Frequency

Word Frequency	*Words*	*Pseudowords*
> 200	16/44	06/44
75–200	12/44	05/43
25–74	09/44	04/44
10–24	11/44	07/44
1–9	06/44	07/44

[4]Note, the display time of 83msec was selected for the free-report task. Given that this exposure duration led to a relatively high level of accuracy with pseudowords in the forced-choice task (0.75), the failure to obtain a WSE may simply reflect a functional ceiling that prevented words from being more accurately identified than pseudowords. However, it should be noted that the WSE obtained with the forced-choice task is relatively small in normal subjects, even when ceiling effects are not an issue.

[5]The number of items in one condition is 43 rather than 44 because IH's attention was diverted during the trial, which was therefore cancelled. This also occurred on two trials in the subsequent WSE experiment.

($\chi^2 = 6.06$, $P < 0.05$), and a similar trend was obtained for the next most frequent words (frequency 75–200) ($\chi^2 = 3.38$, $P < 0.1$). However, lower frequency words were not better identified than matched pseudowords (all $\chi^2 < 2.26$, P values > 0.1). Thus, IH appears to gain specific access to high-frequency lexical–orthographic codes following brief word displays.

Although IH showed an overall WSE, it is important to note that whereas the WSE is unaffected by word frequency in normal subjects (Paap, McDonald, Schvaneveldt, & Noel, 1987), frequency had a profound effect on IH's WSE. Given this discrepancy, it might be tempting to conclude that different mechanisms mediate the WSE in normal subjects and letter-by-letter readers, as suggested by Reuter-Lorenz and Baynes (1991). Another possible interpretation of the present result, however, is that the anomalous WSE in IH was the product of a damaged orthographic lexicon, which is suggested by his surface dyslexic symptoms. In support of this latter position, Behrmann and Bub (1992) described a surface dyslexic patient (MP) who showed a WSE restricted to high-frequency words. In fact, her WSE paralleled her reading performance, because MP was relatively accurate at reading high-frequency irregular words (80%), but her accuracy declined for low-frequency irregular words (20%). Based on these results, Behrmann and Bub argued that the same orthographic representations mediated MP's performance on both tasks, and that her poor performance with low-frequency words reflected selective damage to the orthographic codes of low-frequency words. Note, the same argument applies for IH: He also shows symptoms of surface dyslexia, and he was better able to read high-frequency irregular words (69%) compared to low-frequency irregular words (31%). Accordingly, we would also like to argue that the orthographic codes for low-frequency words are selectively damaged in IH, leading to his poor performance on both the naming task and the WSE when low-frequency items were tested. The extension of this argument, of course, is that when a WSE was obtained, it was mediated by the lexical orthographic codes that supported IH's reading—as is the case with normal subjects.

In contrast with this proposal, it is also possible that orthographic representations (presumably located within his left hemisphere) supported IH's reading performance on high-frequency words, and that perceptual representations (presumably located within his right hemisphere) mediated his WSE, and that both sets of representations are independently damaged (or inaccessible) for low-frequency words. However, we find this latter possibility unparsimonious, and prefer to argue that the same orthographic representations support both phenomena. In this regard, it is worth noting that Reuter-Lorenz and Brunn (1990) reported that a WSE extended to low-frequency words in a letter-by-letter reader who did not show symptoms of surface dyslexia, i.e. a type I letter-by-letter reader (Patterson & Kay, 1982). Accordingly, it appears that a WSE can be obtained for low-frequency words in letter-by-letter readers who have preserved orthographic knowledge of low-frequency words.

The present result highlights the important distinction between type I vs. type II letter-by-letter readers when considering the WSE. In the present experiment, if we had only assessed the WSE for low-frequency items, we would have reached the conclusion that IH fails to show a WSE, a false conclusion given his performance on high-frequency words. Nevertheless, this constraint is not always recognised. Kay and Hanley (1991), for example, reported that a type II letter-by-letter reader identified a similar proportion of words and pseudowords in the free-report task. Based on this result, the authors argued that PD was not able to gain access to the orthographic representations of words, and as a consequence, he was forced to read words in a letter-by-letter fashion from left to right. However, the authors only included low-frequency words in the WSE experiment. Given the Behrmann and Bub (1992) findings as well as the present findings, it does not follow that PD is incapable of showing a WSE. The proper test would include high-frequency words.

One issue that has not been considered to this point is the contribution of guessing to IH's performance in the free-report task. It is worth noting that a guessing strategy would also produce a WSE that is restricted to high-frequency words, since IH can only base his guesses on orthographic knowledge that is preserved—that is, high-frequency words. As noted earlier, we attempted to reduce the likelihood of IH adopting guessing strategies by presenting target items very briefly (83msec), by asking IH to name the letters rather than name words/pseudowords, and by randomly mixing words and pseudowords together. But despite these precautions, it is still possible that guessing influenced performance.

In order to provide a preliminary assessment of IH's guessing strategy, we considered the nature of his errors (cf. Reuter-Lorenz & Brunn, 1990). If a guessing strategy played a role in generating a WSE limited to high-frequency words, then it might be expected that IH's identification errors would tend to be high-frequency words rather than low-frequency words or pseudowords. For example, if IH identified the letters HEA_ from HEAR, a guessing strategy that could produce the obtained WSE would require him to guess high-frequency words such as HEAR or HEAD. If his guesses tended to be low-frequency words such as HEAL, or pseudowords such as HEAB, then his guesses could not contribute to the obtained results. In fact, when words were presented, many of IH's errors were pseudowords (53%), as was the case when pseudowords were presented (58%). More critically, the median frequency of his word errors was only 21 (range between 1 and 1290 occurrences per million; Francis & Kučera, 1982), indicating that IH did not tend to guess with high-frequency words. Accordingly, IH does not seem to be adopting a guessing strategy that would produce a WSE restricted to high-frequency words. Later in this paper, the role of guessing is more directly assessed with a modified version of the Johnston (1978) experiment.

An Assessment of the WSE with Mixed-case Words and Pseudowords

Since a WSE was obtained in the free-report task when words and pseudowords were presented in upper-case letters, we investigated whether a WSE could be obtained with mixed-case items. It is important to note that the size of the WSE in normal subjects is equivalent in these two conditions, and this result has been used to argue that the same representations mediate the WSE and reading (McClelland, 1976). The critical question is whether this is also the case for IH.

The same set of words and pseudowords used in the previous study were included in this experiment, but all items were presented in mixed-case letters. For half of the items, the first letter was upper case (e.g. FiRe), and for half of the items the first letter was lower case (e.g. fAcT). The same procedure was used to display the items, except that words and pseudowords were presented for 133msec rather than 83msec. The longer exposure durations were necessary so that IH could identify approximately 0.30 of words in a free-report task, as determined by a pilot experiment that included a separate set of high-frequency words. Again, the critical question is whether IH would show an advantage in identifying words over pseudowords when the items were presented under the same conditions.

Results and Discussion.

1. *Forced Choice.* The proportions of words and matched pseudowords correctly identified in the various conditions are displayed in Table 4. As can be seen in this table, IH identified a similar number of words and pseudowords; collapsing across frequency, the proportion of items identified was 0.72 and 0.71 respectively. Neither the main effect of lexicality ($\chi^2 < 1$), nor any contrast comparing the identification rate of words and matched pseudowords at each word frequency range was significant (all $\chi^2 < 1.2$). Thus, there is no evidence of a WSE based on the forced-choice results.

TABLE 4
Proportion of Words and Matched Pseudowords Displayed in Mixed-case Letters Identified on the Forced-choice Task as a Function of Word Frequency

Word Frequency	*Words*	*Pseudowords*
> 200	34/44	33/44
75–200	28/44	29/44
25–74	33/43	29/44
10–24	33/44	32/44
1–9	32/43	33/44

TABLE 5
Proportion of Words and Matched Pseudowords Displayed in Mixed-case Letters Identified on the Free-report Task as a Function of Word Frequency

Word Frequency	*Words*	*Pseudowords*
> 200	16/44	10/44
75–200	16/44	06/44
25–74	14/43	05/44
10–24	13/44	10/44
1–9	10/43	07/44

2. *Free Report.* The proportions of words and pseudowords correctly identified in the various conditions are displayed in Table 5. As in the previous experiment, IH's overall accuracy in identifying words (0.31) was greater than in identifying pseudowords (0.17), and this difference was significant ($\chi^2 = 12.06$, $P < 0.01$). Thus, the size of the WSE obtained with mixed-case words (0.14) was equal in size to the WSE obtained with upper-case words (0.12). And once again, the WSE appears to be reduced for low-frequency words: There was a tendency for words with a frequency greater than 200 to be identified better than matched pseudowords ($\chi^2 = 1.97$, $P > 0.1$), and the effect achieved significance for words with frequencies between 75–200, as well as 25–74 (both $\chi^2 > 5.72$, P values < 0.05). However, the WSE for lower-frequency words did not approach significance (both χ^2 values < 1). This result, in combination with the earlier WSE, supports the conclusion that abstract orthographic codes mediated the WSE in IH, because the same effect was obtained when items were displayed in mixed- and upper-case letters. Given the assumption that

word codes within the right hemisphere are case specific, the view that the right hemisphere mediates the WSE is compromised[6].

In order to provide a preliminary assessment of the role that strategic guessing played in IH's performance, we again considered the nature of his errors. As before, if the WSE was a product of a guessing strategy, IH should have a tendency to guess high-frequency words, and thus make word errors of this sort. However, IH showed no such tendency. When presented with a word target, more than half of his errors were nonwords (64%), and when presented with nonwords, he responded with a similar number of nonwords (72%). Furthermore, the median frequency of his word errors was only 19 (range between 1 and 2216 occurrences per million; Francis & Kuçera, 1982).

Direct Assessment of Guessing

Given the nature of IH's errors in the free-report task, there are reasons to doubt that guessing strategies played an important role in the obtained effects. But in order to provide a more direct test of this possibility, we completed one last experiment in which IH was asked to identify a set of high-frequency words that were in high- or low-density orthographic neighbourhoods. Neighbourhood density refers to the number of words that can be constructed from a target by changing one of its letters (Coltheart et al., 1977). So, for example, the word BANK is in a high-density neighbourhood, because many words differ from BANK by one letter—e.g. TANK, SANK, BARK, BAND, etc. (12 in all). By contrast, the word BABY is in a low-density neighbourhood, because only one word can be constructed by changing a single letter from BABY—BABE. If IH adopts a guessing strategy when identifying briefly exposed words, then he should be able to identify words better in low- compared to high-density neighbourhoods, because the identification of just a few letters greatly constrains his guess in the former condition. For example, identifying the letters BAB_ allows IH to make a reasonable guess that

[6] This conclusion is complicated by the fact that words and pseudowords were displayed to IH's left visual field (right hemisphere). In order to maintain the view that the left hemisphere mediated the obtained WSE, we must assume that visual discriptions of the words and pseudowords were transferred to the left hemisphere after being received in the right hemisphere, and that the WSE was obtained only after this transfer took place. Note, this analysis is consistent with the absence of abstract letter priming in the right hemisphere in the callosotomised patient JW, who could not transfer information to the left hemisphere (Reuter-Lorenz & Baynes, 1991). Another account of these findings that we cannot categorically rule out, however, is that they reflect abstract orthographic codes within the right hemisphere that are also capable of supporting a WSE. Future work characterising orthographic representations in the right hemisphere is required in order to resolve this issue.

the target was BABY—BABE is the only alternative. By contrast, guessing should not greatly facilitate the identification of BANK, because the identification of the letters BAN_, for example, only provides a weak clue regarding the target: BANK, BAND, BANG, etc. (cf. Johnston, 1978).

A set of 45 words in high-density neighbourhoods and 45 words in low-density neighbourhoods were selected from the Kučera and Francis (1967) norms. The median number of neighbours in the high- and low-density neighbourhoods were 13.4 and 1.9 respectively, and the frequency of all words was above 50, with mean frequencies of 132 and 138, respectively. Words were presented for 83msec and were masked by an overlaid set of Xs and Os, and once again IH was asked to identify items one letter at a time (same procedure as before). The critical finding was that IH identified a similar number of words in high- (10/45) and low- (5/45) density neighbourhoods ($\chi^2 = 2.0$, $P > 0.1$). Not only is this difference insignificant, but also IH's tendency was to identify words better in high- compared to low-density neighbourhoods, which is *contrary* to what would be expected on a guessing account. Clearly, then, IH does not adopt a guessing strategy in order to facilitate his performance in the identification task.

GENERAL DISCUSSION

The main conclusion that we want to draw from the present set of experiments is that IH accesses lexical–orthographic codes better than is predicted by orthographic-access theories of letter-by-letter reading. Evidence for this conclusion is threefold. First, IH is better able to identify high-frequency words compared to pseudowords in a word superiority experiment, even though items were matched in terms of bigram frequency and neighbourhood density. Given that items were closely matched, it is difficult to argue that IH's reading impairment prevented him from gaining selective access to appropriate lexical–orthographic codes. Furthermore, given the brief displays of the items (83msec in the case of items displayed in upper-case letters), it appears that this selective access was the product of a parallel rather than serial encoding of letters. Second, the WSE was obtained when words and pseudowords were displayed in a mixed-case format. Given that upper- and lower-case letters are treated as functionally equivalent within the orthographic system (e.g. Coltheart, 1981), this finding suggests that orthographic codes, and not visual shape codes, mediated the WSE. And third, IH's naming acuracy for irregular words and his WSE were both reduced for low-frequency items, suggesting that lexical–orthographic codes for high-frequency words supported his reading performance *and* his WSE for these items.

The present findings may also shed some light on the conflicting set of WSE results that have been reported in the literature. As noted in the Introduction, Bub et al. (1989) reported a WSE in a letter-by-letter reader (JV) when words were compared to random letter strings, but unlike IH, the advantage of words over pseudowords did not approach significance. It is important to note, however, that the authors only assessed the WSE in the forced-choice task—the task that failed to support an effect in IH. Accordingly, the different results may be the product of the different test procedures that were employed. Similarly, our finding that the WSE in IH was limited to high-frequency words in the free-report task may explain why Kay and Hanley (1991) failed to obtain a WSE in the patient PD when they only included low-frequency words in their experiment. PD, like IH, suffers from letter-by-letter surface alexia, and accordingly, it is possible that the lexical–orthographic damage suggested by his symptoms of surface dyslexia was responsible for the absence of a WSE. We should emphasise, however, that we are not claiming that all of the discrepancies can be attributed to the different techniques and materials that have been employed across studies. Behrmann et al. (1990), for example, failed to obtain a WSE in DS when high-frequency words and pseudowords were tested on the free-report task, which leads us to believe that this patient lost fast access to all lexical–orthographic knowledge.

The finding that a subset of letter-by-letter readers continue to perform relatively well on a number of covert reading tasks (e.g. Bub & Arguin, 1995; Shallice & Saffran, 1986) or show an intact WSE (e.g. Reuter-Lorenz & Brunn, 1990) raises an interesting issue; namely, how is it that these patients apparently gain rapid access to orthographic knowledge, but continue to read so slowly? Perhaps the best articulated solution to this paradox was proposed by Arguin and Bub (1993; Bub & Arguin, 1995), who attributed DM's lexical decision performance to suboptimal access to representations that normally mediate reading. According to this theory, normal access to letter and word codes depends on activating the correct target, and inhibiting incorrect neighbours. So, for example, in order to read the word GAME it is necessary to access GAME selectively and to inhibit its neighbours—simultaneous access to GAME, DAME, TAME, SAME, etc. would obviously impair reading. Letter-by-letter reading is thought to reflect a dysfunction in the activation and/or inhibition processes that are needed for selective lexical access and, accordingly, the correct orthographic code is always accessed in combination with its neighbours. Slow reading is the consequence (also see Howard, 1991; Shallice & Saffran, 1986).

This account of letter-by-letter reading provides a straightforward explanation for the covert lexical decision times of DM. In the lexical decision task, a subject does not necessarily have to select target items from their neighbours in order to achieve a reasonable level of performance. Rather, all that is required is that subjects distinguish between words and pseudowords. So, as long as words access *more* orthographic codes than pseudowords following damage to the activation/inhibition processes, reasonable performance on a lexical decision task can be achieved. That is, as long as letter-by-letter readers can monitor the overall activation of their orthographic representations, they can make fast lexical decisions. But this activation does not provide sufficient information for reading (cf. Arguin & Bub, 1995; Monsell, Doyle, & Haggard, 1989).

In addition, this approach can accommodate the finding that words and pseudowords are better identified than random letter strings in a word superiority experiment (Bub et al., 1989). By this account, words and pseudowords gain fast (albeit nonspecific) access to orthographic representations, and these codes facilitate the identification of words and pseudowords in comparison to nonwords (McClelland & Rumelhart, 1981). That is, access to specific lexical entries is not thought to be necessary in order to facilitate the identification of words and pseudowords relative to nonwords, because the former items gain access to some orthographic representations, whereas nonwords presumably cannot access any higher-level orthographic knowledge (e.g. XWRN does not have any neighbours to activate).

However, this approach does not provide a straightforward explanation for the present finding that high-frequency words are better identified than pseudowords matched in terms of number of neighbours and bigram frequency. As noted in the Introduction, the standard account of the word/pseudoword difference is that words gain specific access to appropriate orthographic representations (e.g. the word HAND accesses the orthographic code for HAND), whereas pseudowords only access orthographic neighbours and sublexical patterns (e.g. the nonword HANE accesses the orthographic codes for HAND, HATE, LANE, AND, HAN, etc). If letter-by-letter reading is the product of non-selective access to orthographic knowledge, it might have been expected that words and pseudowords would produce similar patterns of diffuse activation within the orthographic system, leading to the diminution of the WSE—a prediction not borne out in the present experiment. Of course, it may be possible to provide an account of the word/pseudoword result within this general framework, but the finding does not follow trivially from the theory.

In order to account for the preserved word/pseudoword advantage, it may be necessary to argue that IH was able to gain selective access to orthographic codes following very brief (83msec) exposure to words, and that these representations facilitated the identification of words compared to matched pseudowords—as is presumed to be the case with normal subjects. If this is indeed the case, then it suggests that IH's letter-by-letter reading must reflect, at least in part, a reading problem after orthographic codes are contacted. This conclusion is inconsistent with current accounts of letter-by-letter reading, all of which adopt some version of the orthographic access approach.

Unfortunately, we are not in a position to offer a post-access theory of IH's reading at present. We can, however, suggest where within the reading system the deficit is located. Given that IH comprehends speech at normal speaking rates, and given that he achieves surprisingly good access to orthographic knowledge from print, we would argue that the procedure for converting orthographic to phonological knowledge is impaired, leading to his slow access to the phonological representations needed for reading. In order to account for IH's reading reaction times that increase as a function of word length, we would also suggest that the damaged orthographic–phonological conversion process is particularly stressed for longer orthographic strings, leading to particularly slow (and error prone) performance with longer words. Of course, much more work is needed in order to evaluate this account of letter-by-letter reading—not to mention the need to specify the nature of this presumed conversion deficit in much more detail. Nevertheless, the present data provide preliminary evidence that IH achieves better access to orthographic codes than is reflected in his overt reading performance, implicating some sort of a post-access deficit.

In closing, we want to emphasise that our post-access account of IH's reading deficit is not intended to be a general claim about letter-by-letter reading. The reading performances of letter-by-letter readers often differ dramatically from one another and, accordingly, there are good reasons to argue that patients often suffer from different underlying deficits (cf. Price & Humphreys, 1992). Perhaps the most striking difference between patients is their reading speed. IH is a relatively mild letter-by-letter reader, in that his reading times only increased by about 500msec per letter, which is similar to patient RAV reported by Warrington and Shallice (1980) and patient DM reported by Arguin and Bub (1993, 1995; Bub & Arguin, 1995). By contrast, some patients read more than an order of magnitude slower than IH (e.g. patient CH from Patterson & Kay, 1982). Given the great differences in the reading speeds among patients, there is no reason to assume that our characterisation of IH will provide insights into the reading disturbance of patients who are much slower readers. But when a patient is able to read relatively quickly, then perhaps post-access accounts should be entertained.

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