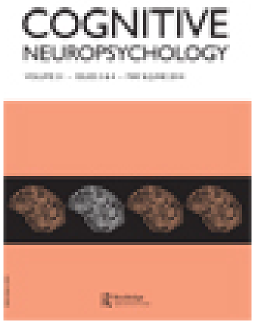

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EXTENT AND LIMITS OF COVERT LEXICAL ACTIVATION IN LETTER-BY-LETTER READING

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The occurrence of implicit reading in brain-damaged patients with letter-by-letter dyslexia suggests a process of covert lexical activation, whereby lexical access occurs on the basis of parallel letter encoding. The extent and limitations of this process were studied by examining masked orthographic and phonological word priming as well as orthographic neighbourhood size effects in letter-by-letter reader IH. In Exp. 1, masked repetition priming occurred with primes displayed in a case-alternate format that were shown for 100 msec (a duration that does not reliably support overt word identification in IH). Under similar exposure conditions, however, primes that are homophones to the target failed to affect performance, in contrast to neurologically intact observers (Exp. 2). Exp. 3 showed that IH's naming latencies are reduced for words with many (vs. few) orthographic neighbours. This result suggests that overt word recognition in the patient is not strictly mediated by sequential letter recognition, but rather that it is conjointly affected by covert lexical activation. Relative to neurologically intact subjects, however, the pattern of the neighbourhood size effect shown by IH as a function of word frequency is abnormal and suggests that lexical activation based on the parallel processing of letters is weakened in the patient compared to normal readers. Overall, results from IH point to a weak form of activation of abstract orthographic lexical representations on the basis of parallel letter encoding, but no significant degree of phonological access. This account is discussed in relation to other similar proposals seeking an explanation of letter-by-letter dyslexia and of the covert lexical activation phenomena that accompany the disorder.

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INTRODUCTION

Letter-by-letter (LBL) dyslexia is an acquired reading disorder that typically follows from a left occipital lesion (Damasio & Damasio, 1983; Déjerine, 1891) and is therefore usually accompanied by right hemianopia. As its name implies, the disorder is characterised by behavioural manifestations suggesting that reading is effected in a serial, letter-by-letter manner, in contrast to the parallel process observed in neurologically intact readers (e.g. Henderson, 1982, for review). Thus, the time required to read a word aloud increases from 500 msec to several seconds (depending on the patient) for each additional letter in the stimulus (e.g. Arguin & Bub, 1993; Bowers, Bub & Arguin, 1996; Farah & Wallace, 1991; Patterson & Kay, 1982; Reuter-Lorenz & Brunn, 1990; Warrington & Shallice, 1980). Consequently, single-word reading latencies are far above those found in normal observers and LBL patients report that reading has become a tedious and very effortful act.

The kind of functional damage that may be held responsible for the clinical symptoms of LBL reading is still a controversial topic. To summarise briefly, here are the main accounts proposed so far for LBL reading: (1) poor perceptual encoding (Farah & Wallace, 1991; Friedman & Alexander, 1984; Kinsbourne & Warrington, 1962; Levine & Calvanio, 1978; Rapp & Caramazza, 1991); (2) deficit in abstract letter identification (Arguin & Bub, 1993, 1994; Behrmann & Shallice, 1995; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990); (3) impaired transfer of letter identities to global orthographic word-forms (Patterson & Kay, 1982); (4) damaged orthographic word-form system (Warrington & Shallice, 1980); (5) impaired access to phonological word-forms following a relatively intact access to orthographic word-forms (Bowers, Arguin, & Bub, 1996). Yet other authors have suggested that LBL reading may not be a unitary syndrome and that, ultimately, the functional impairments causing the disorder may be as varied as the LBL readers themselves (Price & Humphreys, 1992, 1995).

Of interest, and in contrast to the slow sequential letter identification procedure that seems necessary for overt word recognition in LBL patients, a minority of cases paradoxically show evidence suggesting accurate and rapid parallel lexical access for words they cannot identify explicitly. In the first published report of this phenomenon called *implicit reading*, Shallice and Saffran (1986) showed that lexical decisions or semantic decisions in an LBL patient can be performed with an accuracy level that is above chance, even though exposure durations were too short to allow for explicit identification of the stimuli. Similar demonstrations were also reported by Coslett and Saffran (1989) and by Coslett, Saffran, Greenbaum, and Schwartz (1993). Coslett and Saffran (1989) have also shown in two LBL readers that, under limited exposure duration conditions, error rates in the lexical decision task may be independent of word length, in contrast to overt recognition performance. In a more recent study, Bub & Arguin (1995) reported that accurate lexical decisions by an LBL reader can be carried out with response latency being unaffected by word length. It thus appears that, although overt word recognition performance may require the serial identification of letters, lexical or semantic classification in some LBL cases may occur on the basis of parallel letter encoding.

Another demonstration of implicit reading in LBL dyslexia has come from the word superiority effect. In normal observers, the recognition of a briefly exposed letter that is backward masked is superior if it is part of a word than if it is shown in isolation or if it is part of a random letter string (Johnston, 1978; McClelland & Johnston, 1977; Reicher, 1969; Wheeler, 1970). This finding has been reported in some LBL readers, again with exposure durations too short to allow for overt stimulus identification (Bub, Black, & Howell, 1989; Reuter-Lorenz & Brunn, 1990). As with the lexical and semantic classification results, the word superiority effect in LBL readers has been considered as suggesting a rapid access to orthographic word-forms that is mediated by a process other than the serial letter identification involved in explicit word recognition.

What the occurrence of implicit reading suggests is that, besides the slow letter-by-letter process LBL patients seem to require to recognise a word consciously, they may also have access to a lexical access procedure that operates much more rapidly and in parallel, but which cannot reliably support explicit word recognition on its own. We will refer to this putative reading procedure in LBL reading under the term of covert lexical activation.

Covert lexical activation may be assumed to reflect the residual operation of the reading system that has been damaged by the brain lesion (Behrmann, Plaut, & Nelson, this issue; Bub & Arguin, 1995; Bub et al., 1989; Montant, Nazir, & Poncet, this issue; Shallice & Saffran, 1986) or the implication of a separate system that does not provide a significant contribution to reading in normals (Buxbaum & Coslett, 1996; Coslett & Saffran, 1989; Coslett et al., 1993; Saffran & Coslett, this issue). In either case, a detailed characterisation of the extent and limits of covert lexical activation and of the factors that affect its occurrence or magnitude appear crucial for an accurate understanding of LBL reading. Using evidence from implicit reading to obtain such a specification has proven difficult, however, Possibly the most significant obstacle in using implicit reading as a probe into the impaired reading mechanism of LBL readers is the fact that the phenomenon fails to occur in many patients (Behrmann, Black, & Bub, 1990; Behrmann & Shallice, 1995; Howard, 1991; Patterson & Kay, 1982; Price & Humphreys, 1992, 1995; Warrington & Shallice, 1980). From this, one might simply conclude that many LBL patients have no covert lexical activation. Alternatively, this failure may depend on the unusual demands of the implicit reading task rather than on the absence of covert lexical activation. Indeed, by definition, the implicit reading task requires subjects to produce an overt decision about a stimulus they are unable to recognise consciously. As in blindsight, patients may reasonably be reluctant in producing this sort of response, and this would prevent any manifestation of implicit reading altogether. Thus, reasons other than a failure of covert lexical activation may possibly explain past difficulties in demonstrating implicit reading in LBL patients. A similar reasoning has been proposed by Coslett et al. (1993), who showed that the particular strategy adopted by the patient may determine the occurrence of implicit reading.

Besides the implicit reading approach, another way the issue of covert lexical activation may possibly be addressed is through the performance of LBL patients in overt word recognition tasks. Thus, even if serial letter identification appears obligatory for overt word recognition, it remains possible that covert lexical activation may contribute to this performance. Thus, in addition to receiving inputs from a serial letter identification mechanism, the representation system mediating overt word recognition in LBL reading may also receive inputs from that involved in covert lexical activation. Alternatively, overt word recognition in LBL readers may be mediated by the same system as that involved in covert lexical activation. In this case, letter identity information obtained through a rapid parallel process would allow covert lexical activation effects, but this activation would need to be supplemented by serial letter identification in order to permit over word recognition.

The first evidence suggesting that overt word recognition in LBL dyslexia may not always be strictly based on serial letter identification was provided by Howard (1991; but see Behrmann & Shallice, 1995, for discrepant findings). He showed that “fast” reading responses in a visual word naming task resulted from the parallel processing of the constituent letters in the target, but that this process was subject to a significant rate of error. Only when this process failed did patients have to resort to serial letter identification for the overt recognition of a word. This suggests that the lexical activation process assumed to be responsible for implicit reading when it remains covert, may in fact become overt on some proportion of trials, thereby allowing the patient to recognise a word without serial letter processing. When this serial processing is required, however, Howard's results do not indicate whether lexical activation resulting from parallel letter encoding has any contribution to overt word recognition performance.

More recent studies by our group have shown that covert lexical activation may affect overt word recognition performance in an LBL reader. The patient examined in those studies is IH, who suffers from LBL surface dyslexia (Friedman & Hadley, 1992). In a task where the patient was asked to read overtly (i.e. full report) letter strings that were displayed briefly (83 msec) and then masked, recognition accuracy was higher when the stimulus was a word than when it was a nonword (Bowers, Bub, et al., 1996). This lexical effect on overt recognition performance occurred with words and nonwords matched pairwise on orthographic regularity, and a separate experiment discounted an explanation of the results based on guessing. It appears unlikely that these observations can be explained by assuming that explicit stimulus identification was based exclusively on the serial processing of individual letters. Rather, it was proposed that some form of parallel or global encoding of the letter string– i.e. covert lexical activation– must have occurred in IH to allow better identification of the letter string if it formed a word than a nonword.

A separate study examined the effect of briefly exposed primes on IH's overt word recognition performance (Bowers, Arguin, et al., 1996). The subject was shown target words, printed in upper-case, which had to be read aloud. Targets were preceded by a 100 msec lower-case prime and by a 17 msec pattern mask, each displayed in sequence. Items were made of letters that greatly changed shapes between upper- and lower-case formats so that any priming effect could not be a function of the physical overlap between prime and target. Rather, priming effects under such conditions would imply a fast abstract orthographic encoding of the prime[1]. In one experiment, primes were either the same word as the subsequent target or an unrelated word. Correct response times (RTs) were much shorter for targets preceded by an identity prime than by an unrelated prime. A separate experiment showed that this priming effect is highly specific. Indeed, primes that were orthographic neighbours to the target (i.e. words of the same length as the target and differing from it by just one letter; Coltheart, Davelaar, Jonasson, & Benner, 1977) failed to result in any performance benefit relative to unrelated primes. This was true whatever the letter position by which neighbour-primes differed from the target. These priming effects on overt word recognition were obtained under prime exposure conditions (backward masked 100msec exposure) that do not reliably support overt recognition in the patient (see Bowers, Bub, et al., 1996). The results therefore again point to covert lexical activation affecting overt word recognition performance in IH.

The purpose of the present paper is to further study covert lexical activation in LBL reading and to try to characterise it in some detail. As in Bowers, Bub, et al. (1996) and Bowers, Arguin, et al. (1996), we used overt word recognition performance as the measure for covert lexical activation effects. In two experiments, the word priming paradigm of Bowers, Arguin, et al. (1996) served in attempts to establish boundary conditions for covert lexical activation in LBL reading. In a third experiment, the effect of orthographic similarity of the target to other words of the vocabulary was used as an index of covert lexical activation.

CASE REPORT

The patient who took part in the present experiments is IH. The word superiority and abstract word priming experiments of Bowers (Bowers, Arguin, et al., 1996; Bowers, Bub, et

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[1] The occurrence of priming under these conditions may also conceivably reflect activation of the phonological, semantic, or other high-level representations of the prime. However, it is assumed here that such access from a visual written input must be mediated by an internal orthographic representation of the stimulus. To avoid overestimating the reading capacities suggested by priming effects in an LBL patient, we will therefore only assume access to the lowest level of representation that may mediate the relation between the prime and the target as the cause of priming.

al., 1996) that are described in the previous paragraphs have been conducted on IH, and details of his clinical status can be found in those publications. We will therefore only briefly summarise his condition. IH is a right-handed English-speaking male who was 56 years of age at the time of testing. At the age of 43, in 1983, IH suffered from a subarachnoid haemorrhage that was drained surgically. No CT or MRI scan is available but the neurological report indicates that the haematoma was located in the left temporo-occipital area. IH's behavioural complaints are of a complete right-homonymous hemianopia, anomia, surface agraphia, and reading problems. The patient's reading latencies average at about 1200–1500msec for 4-letter words and increase linearly by about 500msec each additional letter in the word. Therefore, the patient shows the characteristic clinical symptoms of LBL reading. IH's reading performance is also affected by lexical frequency and by the regularity of spelling-to-sound correspondences. Thus, word naming accuracy for regular words average about 85% correct across a vast range of word frequencies and this latter variable had no effect on accuracy. In contrast, accuracy on irregular words was of 69% correct with high-frequency items but performance dropped to 31% correct for low-frequency items. Such an interactive effect of frequency and regularity has been reported previously in surface dyslexics and suggests that IH suffers from a combination of LBL reading and surface dyslexia, a disorder called letter-by-letter surface dyslexia by Friedman and Hadley (1992).

EXPERIMENT 1

Bowers, Arguin, et al. (1996) have shown that a four-letter upper-case target word, preceded by the same word printed in lower-case, displayed for 100msec, and then masked, results in marked RT reductions compared to targets preceded by an unrelated prime. In those experiments, there was little overlap between the visual features of the lower-case prime and the upper-case target, which suggested that the priming effect was mediated by an orthographically abstract covert lexical activation procedure. Just how abstract this covert lexical activation is remains to be determined, however.

One hypothesis is that the covert lexical activation that mediates priming corresponds to the orthographic encoding process generally assumed to mediate normal reading. By this hypothesis, each letter of the prime is encoded in parallel as an abstract orthographic identity and these letter identities are transferred to an abstract lexical representation system. Thus, it would be the activation of the abstract orthographic representation of the prime that is responsible for the beneficial effect of identity priming on recognition of the target word. A viable alternative hypothesis, however, is that priming is mediated by shape-specific lexical knowledge. According to this view, the patient would have access to stored representations of word shapes under their lower-case and upper-case formats and the activation of a word in one of these formats by the prime would then transfer to the representation of the same word under the other format (see Boles, 1992;

Boles & Eveland, 1983, for a similar proposal for abstract letter recognition). This activation transfer between shape-specific representations of the same word would therefore be the process responsible for the priming effects previously observed in IH.

One way to distinguish between abstract orthographic vs. shape-specific word encoding as the process mediating word priming in LBL dyslexia is to present primes printed in an alternation of upper- and lower-case letters. According to the hypothesis that covert lexical activation is based on a shape-specific reading mechanism, the occurrence of priming depends on the prior existence of stored shape-specific word representations that match the surface features of the prime and the target that are presented. Words printed in a case-alternated format are not part of the normal reading environment and thus should not have prior shape-specific representations. Using such words as primes therefore should not result in any priming effect if covert lexical activation is based on a shape-specific lexical code. In contrast, the priming effect should still occur with case alternated primes if covert lexical activation is mediated by a truly abstract orthographic encoding operation. It has been reported by Forster and Guess (1996) that masked priming effects are unaffected by the case alternation manipulation in neurologically intact observers.

The contrast between the rival hypotheses of abstract orthographic vs. shape-specific word encoding to account for the word priming results in IH relates to recent findings about the left- and right-hemisphere orthographic encoding mechanisms that mediate reading. In a word repetition priming task conducted with neurologically intact observers, Marsolek and his collaborators (Marsolek, Kosslyn, & Squire, 1992; Marsolek, Squire, Kosslyn & Lulenski, 1994) have reported greater priming with displays to the right than to the left hemisphere if stimulus shape remained constant between study and test. However, if stimulus shape was changed (upper-case vs. lower-case print) between study and test, the priming effect was reduced with right-hemisphere stimulation to become equal to that for the left hemisphere, which was unaffected by the shape change manipulation. From these observations, the authors concluded that two separate systems contribute to visual word recognition, one that is abstract with respect to visual shape and another that is shape specific. Further, although both hemispheres would implement an abstract orthographic system, it was proposed that the shape-specific system operates more effectively in the right than the left hemisphere. This interpretation, it should be noted, implies that the full magnitude of the priming effects observed is exclusively attributable to the hemisphere to which stimuli were directed in the test phase. This need not be so, however, since neurologically intact subjects are capable and likely to transfer information between their cerebral hemispheres in a reading task where stimuli are lateralised. Assuming such transfer may have occurred, the alternative hypothesis of exclusive capacities for abstract orthographic encoding and for shape-specific encoding in the left and right cerebral hemispheres, respectively, is just as consistent with the data as the interpretation suggested by Marsolek and collaborators. By this alternative account, information about right-hemisphere stimuli was transferred early to the left hemisphere after an initial shape-specific encoding. While this right-hemisphere shape-specific mechanism would be responsible for the greater priming effect with right-hemisphere stimuli when shape remained constant between study and test, all the other components of the priming effects observed would be attributable to the abstract mechanism of the left hemisphere. A separate set of observations from a subject in whom inter-hemispheric transfer was impossible argues for our alternative interpretation of the Marsolek et al. data.

Reuter-Lorenz and Baynes (1992) studied split-brain patient JW in a task comparing the effects of abstract and physical identity primes on the recognition of a subsequent lateralised target letter. In this experiment, JW showed benefits from abstract and physical identity priming with left-hemisphere stimuli, but only physical identity priming with right-hemisphere stimuli. These observations suggest that, without the benefit of inter-hemispheric transfer, written stimuli exposed to the right hemisphere are represented under a shape-specific code only[2]. It seems clear that further work will be requited to elucidate fully the issue of hemispheric asymmetries in orthographic representation. However, to the degree that the available relevant data can be considered meaningful, it appears the conditions of the present experiment may help determine the lateralisation of covert lexical activation in IH. Thus, the lack of a priming effect with case-alternated primes in IH would strongly suggest that covert lexical activation is mediated by the right hemisphere. In contrast, a substantial priming effect under the conditions of Exp. 1 would suggest that the left hemisphere may be largely responsible for covert lexical activation effects in the patient.

This issue of hemispheric asymmetries in reading mechanisms is particularly relevant in the study of covert lexical activation in LBL readers. Indeed, resolution of this issue would indicate whether covert lexical activation is

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[2] One may conceive this suggestion as being contradictory to observations by Saffran (Saffran, 1980; Saffran & Marin, 1977); they reported accurate reading performance with case alternated words in deep dyslexic patients, who are assumed to recognise words via their right hemispheres. The contradiction may be more apparent than real, however. Indeed, none of the deep dyslexic patients examined in those studies had a complete left hemianopia. In fact, three out of the four cases reported had normal visual fields whereas the other showed a right upper quadrant defect. Taken in conjunction with the fact that stimuli were presented in free vision, it is quite conceivable that abstract orthographic encoding of the words may have been performed by the left hemisphere and that the contribution of the right hemisphere in the reading performance of these patients only emerged at the stage of lexical access. In defence of this view, it may also be noted that all the signs suggesting a contribution of the right hemisphere in the reading performance of deep dyslexics concern the form of the lexical representations instantiated by that hemisphere, not the mechanisms involved in orthographic encoding.

based on the residual function of the system that mediated reading prior to the occurrence of brain damage (i.e. left hemisphere), or whether it implicates another system that contributes little to reading performance in neurologically intact individuals (i.e. right hemisphere). Studies by Coslett, Saffran, and their collaborators have suggested that the residual reading abilities of LBL readers may be mediated by the right hemisphere. Thus, high-imagery words tend to be read better than low-imagery words and concrete nouns tend to be read better than function words (Coslett & Saffran, 1989; Coslett et al., 1993). Furthermore, in a more recent experiment, transcranial electromagnetic stimulation applied over the posterior portion of the right hemisphere was found to disrupt overt word recognition in an LBL patient (Coslett & Monsul, 1994). This sort of evidence has led to the proposal that the putative right hemisphere contribution to word recognition in LBL patients may extend to implicit reading as well. Resolution of the issue of hemispheric contributions to covert lexical activation is crucial for our understanding of the phenomenon and for the design of rehabilitation attempts for the disorder.

In Exp. 1, we contrasted the rival hypotheses described earlier as to the process mediating covert lexical activation. The word priming procedure used was similar to that of Bowers, Arguin, et al. (1996). However, rather than preceding the upper-case target by a lower-case prime, primes in the present experiment were printed in an alternation of lower- and upper-case letters.

Methods

Subjects were IH and a group of 8 neurologically intact individuals (3 males, 5 females) aged between 18 and 20 years. The latter subjects served to determine that the results expected from an intact mature reading system actually occurred under the experimental conditions that were used. All trials began with a 1500msec rectangular 1.0cm (1.1° of visual angle, from a viewing distance of about 50cm) high × 3.5cm (4.0°) wide pattern mask made of a chequerboard with 1mm black and white elements, which was displayed at the centre of the computer screen. Subjects were requested to keep their eyes fixated at the rightmost extremity of the chequerboard. This procedure was required to ensure that the entire length of the primes and targets was within the normal portion of IH's visual field. All stimuli that followed the initial mask were also centred on the middle of the screen and the primes and targets all had vertical and horizontal extents that were inferior to those of the mask. Immediately following (i.e. 0msec interstimulus interval) the initial mask, a 100msec prime-word was displayed. It was then immediately followed by the pattern mask shown for 17msec, which immediately preceded target exposure. Targets (*N* = 60; Appendix A) were 4-letter upper-case words displayed within a rectangular 1.0cm (1.1°) high × 3,5cm (4.0°) wide frame and they remained visible until response. The subject was instructed to name the target aloud as rapidly as possible while avoiding errors. Half of the targets were high-frequency words (range 50–761 occurrences per million; average

= 239; Kucera & Francis, 1967) and the other half were low-frequency words (range: 3–20 occurrences per million; average = 9). High- and low-frequency targets were matched pairwise on single-letter (average sum across words = 2100.5) and bigram frequencies (average sum across words = 211.8; Mayzner & Tresselt, 1965) and on their numbers of orthographic neighbours (average = 9.9; words of the same length as the target that differ from it by a single letter; Coltheart et al., 1977). Targets were selected so that at least three of their component letters had very different shapes between upper-case and lower-case formats (a/ A, b/ B, d/ D, e/ E, g/ G, l/ L, m/ M, q/ Q, r/ R; Boles & Clifford, 1989). We also attempted to avoid targets with irregular spelling-to-sound correspondences because of the patient's difficulty in reading such stimuli aloud. Overall, the target list comprised three high-frequency and two low-frequency targets that were irregular. Primes were printed in an alternation of upper- and lower-case letters and were either the same word as the target (Repeated) or a different word with no orthographic overlap with the target (Unrelated). Unrelated primes were taken from the same frequency range as the target and each target was tested under both priming conditions. The first letter of half the primes in each condition was lower-case and the other half began with an upper-case letter. All stimuli appeared in black over a white background. Written stimuli were printed in Helvetica 24-point bold font. Responses were registered by a voice-key connected to the computer controlling the experiment. After each response, the experimenter registered the subject's utterance via the computer keyboard and then triggered the next trial by a keypress. To ensure enough observations per condition, each subject was administered the complete set of prime-target pairs twice. Across administrations, the case alternation of primes was inverted such that, for instance, the prime word "band" was printed "BaNd" on one administration and "bAnD" on the other. In IH, these administrations were conducted in different sessions separated by an interval of 2 weeks. In normal subjects, the order in which the lists were repeated was counterbalanced. Throughout the experiment with IH, a total of 4 trials (1.6%) were lost due to the failure of the subject's response to trigger the microphone. Across all trials run with neurologically intact subjects, 24 trials (1.3%) were lost due to a microphone error. These trials were not considered in the data analyses.

Results

Average correct response times (RTs) and error rates observed in neurologically intact subjects are shown in Figs. 1 and 2, respectively. The correlation between RTs and error rates was of -0.26 (n.s.), which indicates no speed-accuracy trade-off. For each subject, RTs that were more than three SDs away from the mean for their condition were discarded. A total of 49 data points (2.6% of trials) were removed from the analysis on this criterion. A two-way ANOVA of Priming (Repeated vs. Unrelated) × Frequency (Low vs. High) showed main effects of priming [$F(1, 7) = 25.0$; $P < .005$] and a

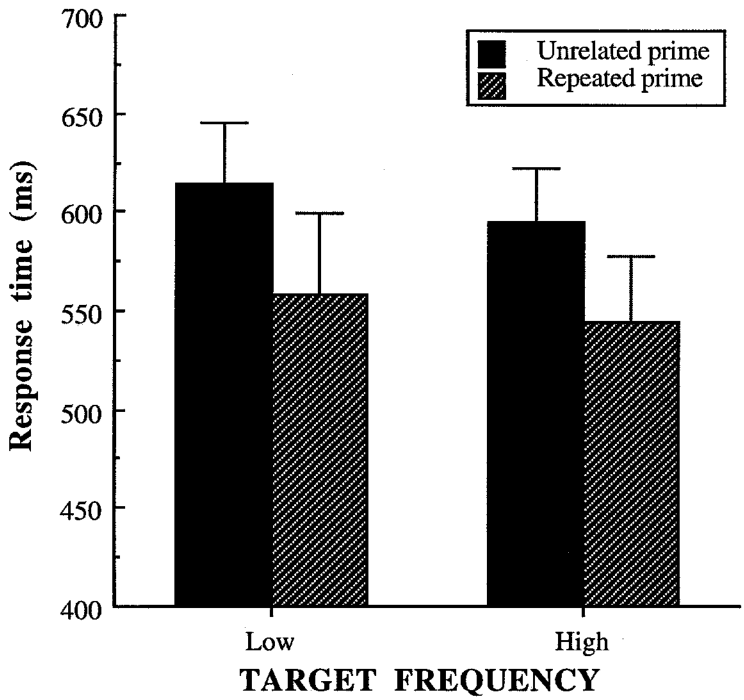

Fig. 1. Average correct RTs to low- and high-frequency targets preceded by unrelated or repeated case-alternated primes in neurologically intact subjects (Exp. 1).

marginally significant effect of frequency [$F(1, 7)=5.0$; $P < .07$], but no interaction [$F(1, 7) < 1$]. The main effect of priming indicates shorter RTs in the Repeated than in the Unrelated condition and the trend for a frequency effect suggests shorter RTs with high- than low-frequency targets. The ANOVA applied on error rates showed no significant effect of priming or of frequency, and no interaction [all Fs$(1, 7) < 1$].

For IH, average correct RTs are shown in Fig. 3 and error rates are presented in Fig. 4. The correlation between RTs and error rates was of −0.17 (n.s.), which indicates no speed-accuracy trade-off. Four data points (1.7% of trials) were removed from the RT analysis because response latencies were more than three SDs away from the mean for their condition. A two-way ANOVA of Priming (Repeated vs. Unrelated) × Frequency (Low vs. High) showed a main effect of priming [$F(1, 176) = 10.1$; $P < .005$] but no main effect of frequency [$F(1, 176) = 1.5$; n.s.] and no interaction [$F(1, 176) = 2.7$; n.s.]. The main effect of priming indicates shorter RTs in the Repeated than in the Unrelated condition. Analysis of error rates showed no effect of priming [$\chi^2(1) = 1.6$; n.s.], but a higher error rate with low- than with high-frequency targets [$\chi^2(1) = 5.1$; $P < .05$].

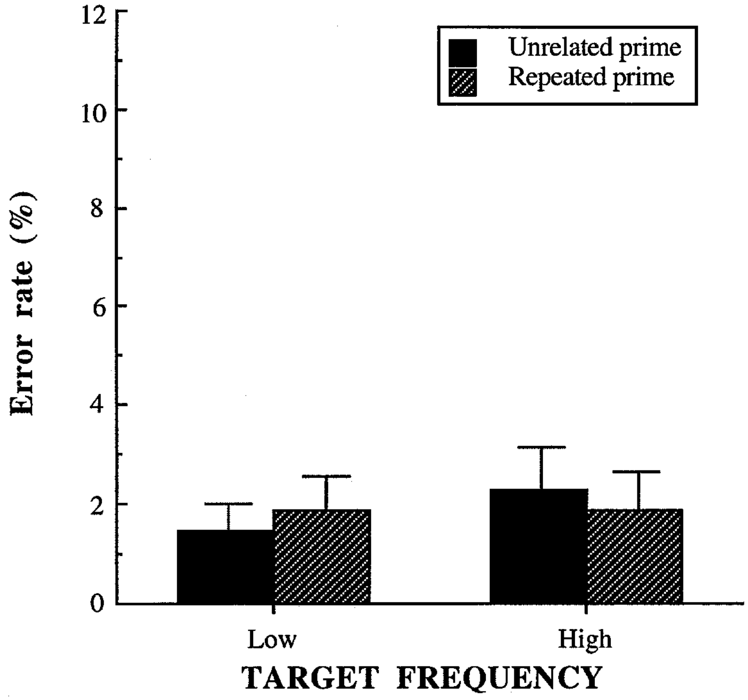

Fig. 2. Percentage error rates to low- and high-frequency targets preceded by unrelated or repeated case-alternated primes in neurologically intact subjects (Exp. 1).

Discussion

The results of Exp. 1 show that a word prime printed in a case-alternated format and displayed for 100msec markedly affects reading latency for an upper-case target word both in neurologically intact observers and in an LBL reader. Specifically, reading latency was reduced if the prime was the same word as the target rather than an unrelated word. The observations from IH replicate the abstract word priming effect, previously reported by Bowers, Arguin, et al. (1996) with primes printed in lower-case and targets in upper-case letters. Although the absolute magnitude of the priming effect observed in Exp. 1 in IH is substantially larger than in normal subjects, the size of priming effects relative to overall average correct RTs is highly similar, with an effect size of 10.0% for IH and of 10.9% for normals. The indication is thus that IH was as sensitive to the case-alternated primes as were neurologically intact subjects.

There are indications that the priming effect observed in IH was not mediated by the overt recognition of the prime. In IH, the display of a word for 100msec, which is then followed by a pattern mark, is insufficient to reliably support overt identification. Thus, with 133msec masked exposure, IH's word recognition accu-

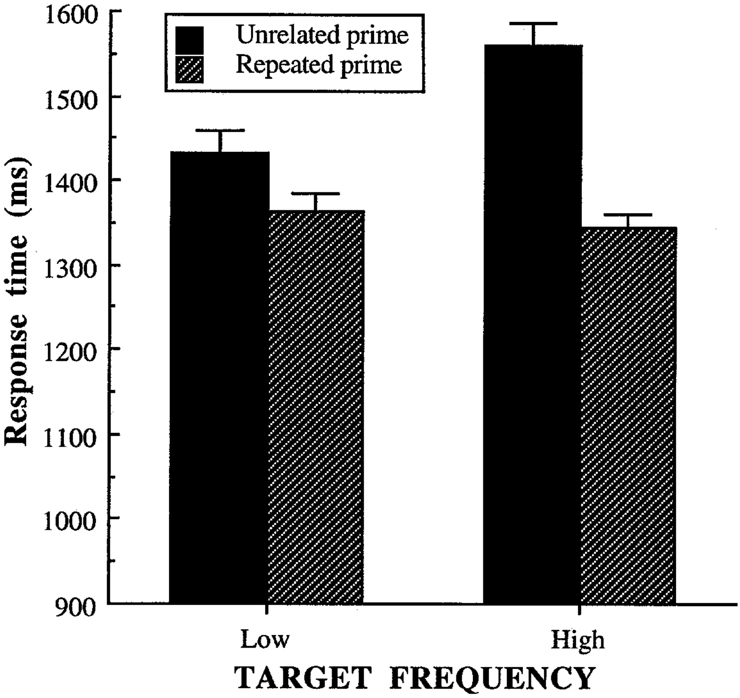

Fig. 3. Average correct RTs to low- and high-frequency targets preceded by unrelated or repeated case-alternated primes in IH (Exp. 1).

racy is only about 30% (Bowers, Bub, et al. 1996). In addition, IH never spontaneously reported seeing anything prior to the target and, when asked by the experimenter, he indicated he only occasionally saw a brief flash but that he had no idea what it could be. In spite of this, however, it could still be argued that there may have been a small proportion of trials on which IH was able to consciously recognise the prime and that only these trials are responsible for the priming effect observed. On this view, the failure of the patient to report even seeing the prime could be explained by a problem with memory, not perception. What the argument would predict, though, is that the distribution of IH's correct RTs with repeated primes should be bimodal. Thus, one portion of the RT distribution should comprise a number of very short response latencies corresponding to trials where the prime was consciously recognised and priming occurred. These trials should be segregated from the remainder, where RTs are much longer because the prime was not recognised consciously and therefore that no priming occurred. An analysis of the response latency distribution with repeated primes for IH fails to support this prediction of a bimodal distribution. Figure 5 shows the histogram of IH's actual RT distribution with repeated primes against the log-normal distri-

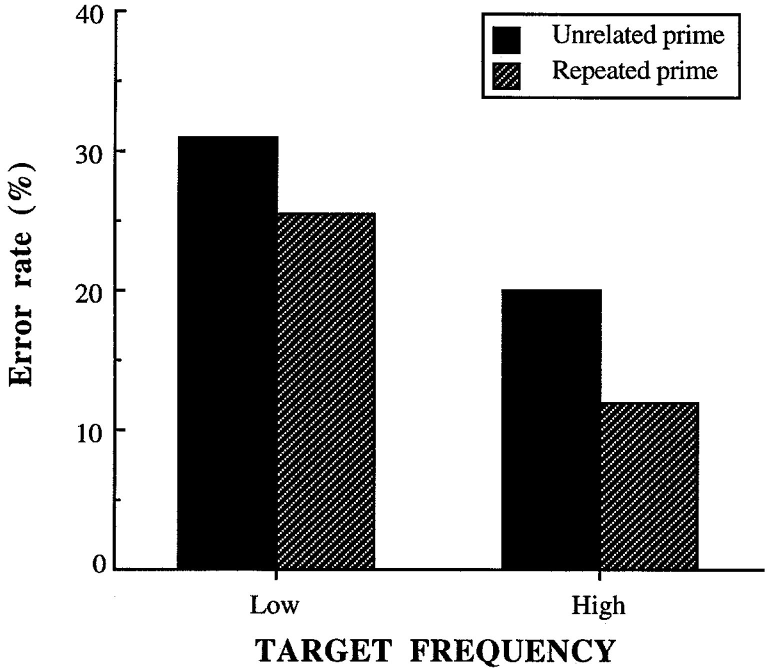

Fig. 4. Percentage error rates to low- and high-frequency targets preceded by unrelated or repeated case-alternated primes in IH (Exp. 1).

bution. Both distributions are highly similar and a Kolmogorov-Smirnov test indicates no difference between the two (D = 0.08; $P > .20$). Most importantly, the RT distribution shown by IH is quite distinct from the bimodal distribution that is predicted by the assumption that any priming effect observed in the patient is only due to the overt recognition of some proportion of the primes.

The central motivation for Exp. 1 was to determine the kind of orthographic encoding procedure on which covert lexical activation is based in IH. Results from Bowers, Arguin, et al. (1996) indicated that the priming effect mediated by covert lexical activation is orthographically abstract since it occurred with primes printed in lower-case and target printed in upper-case and with items made of letters that greatly change shapes across case. Still, as indicated earlier, priming under those conditions could have been based on shape-specific lexical codes rather than on the abstract encoding of letter identities. With primes printed in a case-alternated format as in the present experiment, the former theory predicted no priming effect since it may be reasonably assumed that shape-specific lexical representations for case-alternated words are not available to the patient. Contrary to this prediction, robust priming was found with case-alternated primes. This suggests that covert lexical activation in IH is based on an

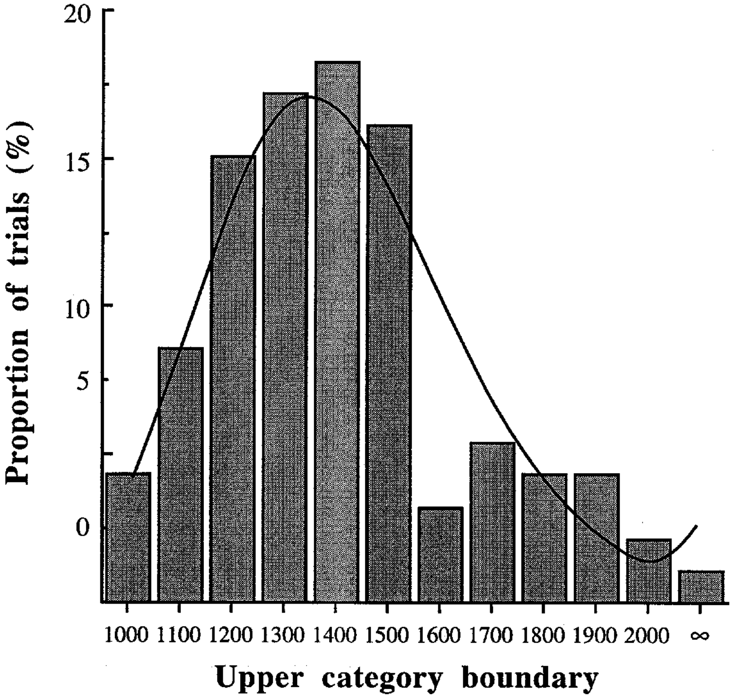

Fig. 5. Distribution of IH's correct RTs with repeated primes (histograms) against the log-normal distribution (continuous curve).

abstract orthographic encoding procedure, whereby the identity of each letter of the stimulus is determined rapidly while discarding visual shape information. This form of orthographic encoding corresponds to what is generally assumed to occur in normal readers, thus suggesting that covert lexical activation in IH may rest on the residual function of the system on which reading was based prior to the occurrence of brain damage.

Another issue of concern for Exp. 1 was that of the cerebral lateralisation of the covert lexical activation procedure assumed to mediate the word priming effect as well as implicit reading phenomena in LBL dyslexia. According to the interpretation presented earlier for the results of studies by Reuter-Lorenz and Baynes and by Marsolek and his collaborators, the left cerebral hemisphere is clearly dominant in performing abstract orthographic encoding of written stimuli whereas the right hemisphere would mainly, if not exclusively, rely on shape-specific representations. The kind of abstract encoding denoted by the priming effects shown by IH seems incompatible with covert lexical activation being mediated by the assumed shape-specific representation system of the right hemisphere. Rather, given what is presently known of the orthographic encoding capacities of the left and right cerebral hemispheres of split-brains and of neurologically intact individuals, the present results appear more compatible with the hypothesis that covert lexical activation in IH depends on the residual component of the left hemisphere's abstract orthographic encoding mechanism. The diagnostic criterion used here to identify the hemisphere responsible for covert lexical activation effects in LBL reading is new and of potential interest for further investigations. It should be acknowledged, however, that the hypothesis of covert lexical activation being mediated by the left cerebral hemisphere presently rests on relatively weak ground and that a firm conclusion regarding this issue must await further investigations of the relative capacities of the cerebral hemispheres for orthographic encoding.

One aspect of the results of Exp. 1 that is difficult to interpret concerns the effect of lexical frequency and its interaction with priming. Under a strict interpretation of the outcome of the data analyses where only differences with $P < .05$ are considered real, IH only differs from normal observers by the fact that his reading accuracy is lower for low-frequency than high-frequency words. However, there are weaker aspects of the data that suggest more fundamental differences between IH and normal observers regarding the lexical frequency effect. It was noted that normal subjects showed a marginally significant reduction of RTs with high-relative to low-frequency words, whereas no indication for such an effect was present in IH. Furthermore, whereas it is clear that neurologically intact subjects showed a priming effect of equal magnitude with high- and low-frequency words, Fig. 4 suggests that priming in IH may have been somewhat weaker with low-frequency words. What seems to be a major reason for the failure of the RT data analysis in IH to demonstrate such an interaction is the fact that it was based on relatively few trials, given the subject's elevated error rates with low-frequency words. Another, more general reason that may have prevented the observation of clear and consistent data with respect to lexical frequency is the relatively weak manipulation of this factor in Exp. 1. Indeed, whereas low-frequency words had an occurrence frequency ranging between 3 and 20 per million, the lower bound for high-frequency words was of only of 50 occurrences per million. In Exp. 3, described below, a much larger lexical frequency discrepancy is used between low- and high-frequency words and the results regarding the effect of this factor are rather clear-cut in showing an abnormal effect of lexical frequency on covert lexical activation in IH.

Based on the word priming studies conducted so far with IH, no clear limit on the capacity of covert lexical activation has emerged. Thus, a priming effect of normal magnitude occurred with 100msec primes printed in a case-alternated format and priming occurred for both low- and high-frequency words (see also Bowers, Arguin, et al., 1996, for priming effects as a function of word frequency). Moreover, as shown in Bowers, Arguin, et al., the word priming effect is highly specific since it does not generalise to orthographic neighbours. This suggests that the 100msec masked primes used result in a very accurate activation of abstract orthographic word forms. However, provided that the covert lexical activation assumed to mediate the word priming effect bears any relation to the overt word recognition performance of the patient, as argued in the Introduction one should eventually be able to find a limit to the capacities of covert lexical activation, which would signal an abnormal functional bottleneck that may be at the origin of the LBL disorder. One such limit, suggested by Bowers, Arguin et al., is access to phonological representations of words. It is conceivable that failure of such access may be responsible for the reading deficit in LBL dyslexia, although it would not prevent fast abstract orthographic priming effects such as those noted so far in IH. Experiment 2 provides a test of this possibility by examining phonological priming.

EXPERIMENT 2

To assess the possibility that phonological access constitutes a significant limit on the covert lexical activation process in IH, Exp. 2 used a word priming procedure similar to that used in Exp. 1. The same set of targets was tested under repeated, unrelated, and homophone priming conditions. In the last condition, the prime was orthographically distinct from the target but was homophonic to it. Previous research in neurologically intact observers has shown robust benefits from primes that are homophones to the target in a word naming task (Lukatela & Turvey, 1994).

Methods

Subjects were IH and a group of 15 neurologically intact individuals (5 males, 10 females) aged between 18 and 20. As for Exp. 1, the latter subjects served to determine that the results expected from an intact mature reading system actually occurred under the experimental conditions used here. The procedure was the same as in Exp. 1, except that primes were printed in lower-case letters whereas targets were printed in upper-case letters. Targets (Appendix B) were 44 four- and five-letter words, ranging in frequency from 1 to 298 per million, which had at least three of their component letters with very different shapes between upper- and lower-case formats (a/ A, b/ B, d/ D, e/ E, g/ G, l/ L, m/ M, q/ Q, r/ R). Because of the patient's difficulty in reading irregular words, these were avoided as much as possible. Only three of the targets used in Exp. 2 have irregular spelling-to-sound correspondences. Each target was tested under three priming conditions. Repeated: the prime was the same word as the target; Unrelated: the prime was a word of the same length as the target but had no orthographic overlap and was phonologically different from the target; Homophone: the prime was a word orthographically different from the target but had the same pronunciation (e.g. prime = gait; target = GATE). The complete trial list comprised 3 blocks of 44 trials with no target repeated within a block. To ensure enough observations per condition, each subject was administered the complete stimulus list twice. For IH, these repeated administrations occurred in different sessions separated by an interval of 2 weeks. The order in which blocks were run with neurologically intact subjects was counterbalanced across subjects. For IH, a total of three trials (1.1%) were lost due to the failure of the subject's response to trigger the microphone. Across all trials run with neurologically intact subjects, 17 trials (0.9%) were lost due to a microphone error. These trials were not considered in the data analysis.

Results

Average correct RTs and error rates observed in neurologically intact subjects are presented in Figs. 6 and 7, respectively. The correlation between RTs and error rates was exact and positive (+ 1.00, $P < .05$), which indicates no speed-accuracy trade-off. For each subject, RTs that were more than 3 SDs away from the mean for their condition were discarded. A total of 37 data points (1.9% of trials) were removed from the analysis on this criterion. An ANOVA carried out on correct RTs showed a significant effect of priming [$F(2,28) = 21.3$; $P < .001$]. RTs with Repeated and Homophone primes were both significantly lower than those with Unrelated primes [$t(28) = 5.9$; $P < .001$; $t(28) = 4.1$; $P < .005$; respectively]. In addition, RTs with Repeated and Homophone primes did not differ significantly $t(28) = 1.6$; n.s.]. The analysis performed on error rates showed no effect of priming [$F(2,28) < 1$]. Thus, although perfectly correlated with RTs, error rates were very low (overall average of 1.4%), and the difference between any pair of conditions did not exceed 1%.

Average correct RTs and error rates for IH are shown in Figs. 8 and 9, respectively. The correlation between RTs and error rates was of + 0.65 (n.s.), which indicates no speed-accuracy trade-off. For IH, no correct response latency was found which was more than 3 SDs away from the mean for its condition. An ANOVA carried out on correct RTs showed a significant effect of priming [$F(2,222) = 6.1$; $P < .01$]. RTs with Repeated primes were shorter than those with Unrelated [$t(222) = 3.5$; $P < .001$] or Homophone primes [$t(222) = 2.0$; $P < .05$]. By contrast, RTs with Homophone and Unrelated primes did not differ significantly [$t(222) = 1.5$; *n.s.*]. The effect of priming on error rates was not significant [$\chi^2(2) = 2.4$; *n.s.*].

Discussion

The results of Exp. 2 replicate the abstract word repetition priming effect previously observed in IH. The magnitude of the repetition priming effect (relative to Unrelated primes) shown by the patient in relation to overall correct RTs is slightly higher (12.9%) than that observed in neurologically intact subjects (9.5%), thus indicating that IH was at least as sensitive to the word repetition effect as were normal individuals. However, whereas neurologically intact subjects also showed a substantial RT benefit with Homophone primes relative to Unrelated primes, thereby replicating previous observations by Lukatela and Turvey (1994), the difference between these conditions was not significantly for IH.

The occurrence of a homophone priming effect in neurologically intact observers im-

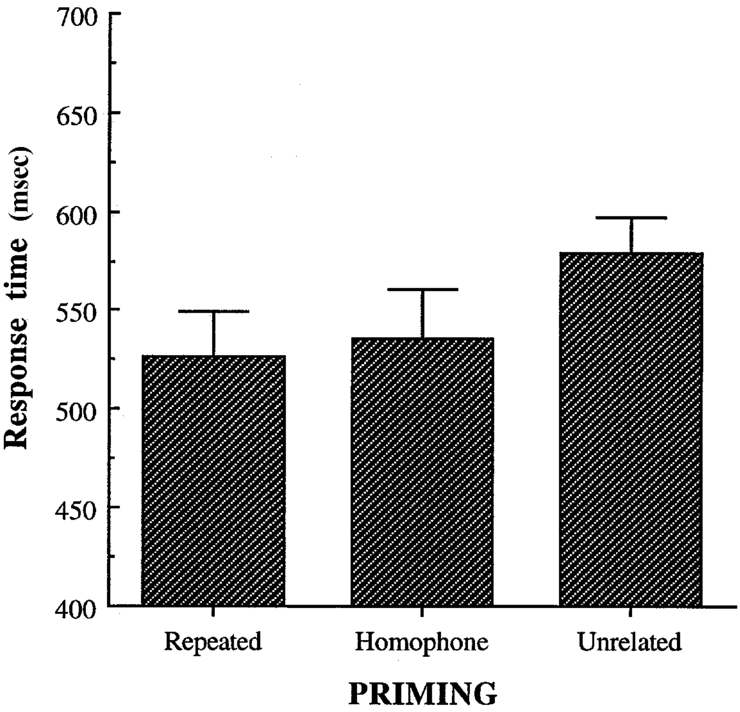

Fig. 6. Average correct RTs to targets preceded by repeated, homophone, or unrelated primes in neurologically intact subjects (Exp. 2).

plies the advance activation of the phonological representation of the target by the prime. That this effect failed to occur in IH indicates that covert lexical activation fails to reach the phonological representations of words. This limit on covert lexical activation in IH, which was initially hypothesised by Bowers, Arguin, et al. (1996), was proposed by these authors as the basic cause for LBL reading in the patient. Thus, in light of repetition priming results, which showed no clear limitation on orthographic encoding capacity in IH, it was proposed that the source of the LBL reading disorder must lie further in the processing stream involved in overt word recognition and one obvious candidate was phonological access. Thus, according to this proposal, it is a failure in the transfer of an intact global orthographic activation to phonological representations of words that would prevent normal reading performance in IH and force the patient to resort to what appears as a letter-by-letter decoding strategy. The results obtained here in Exps. 1 and 2 are largely consistent with this theory. Thus, neither experiment suggests a significant aberration in the patient's capacity for orthographic encoding, but Exp. 2 clearly argues for a failure of phonological access. What constitutes an important difficulty with this view, however, is

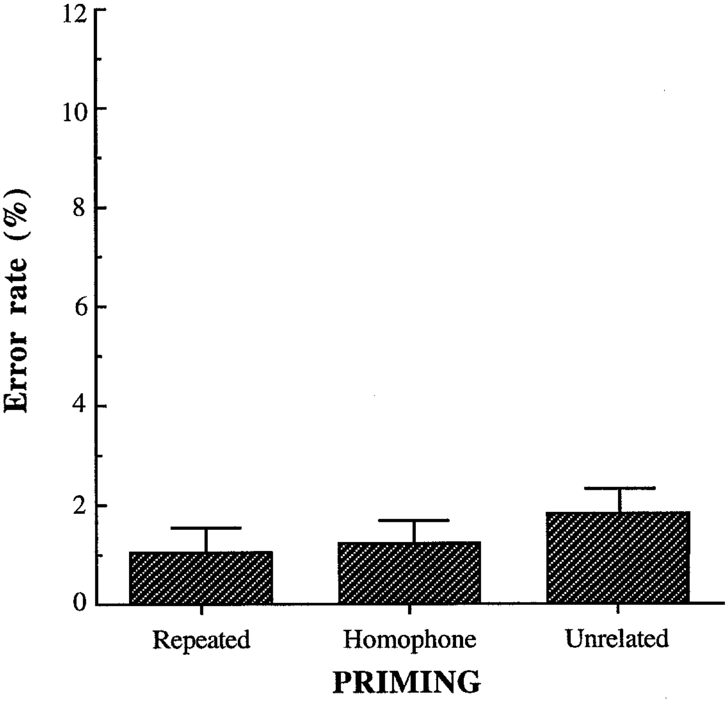

Fig. 7. Percentage error rates to targets preceded by repeated, homophone, or unrelated primes in neurologically intact subjects (Exp. 2).

that its viability is largely dependent on the absence of anomalous findings with respect to orthographic encoding; i.e. on negative results. Stronger support for the proposal of Bowers, Arguin, et al. (1996) may then require additional, and possibly more stringent tests of orthographic encoding capacity in IH.

Exp. 3 will provide a further assessment of the assumption of intact orthographic encoding processes in IH. However, the method used will be quite different from the priming paradigm we have applied so far. Thus, the task will simply consist in reading words aloud and, instead of the word priming effect, the index for covert lexical activation as modulating overt recognition performance will be based on the facilitatory effect of increased orthographic neighbourhood size.

EXPERIMENT 3

Previous studies of visual word recognition in neurologically intact observers have shown that the orthographic similarity of a target with other words of the vocabulary affects the time required to recognise it. In particular, it has been shown that targets with many orthographic neighbours (i.e. other words of the same length that differ from it by just one

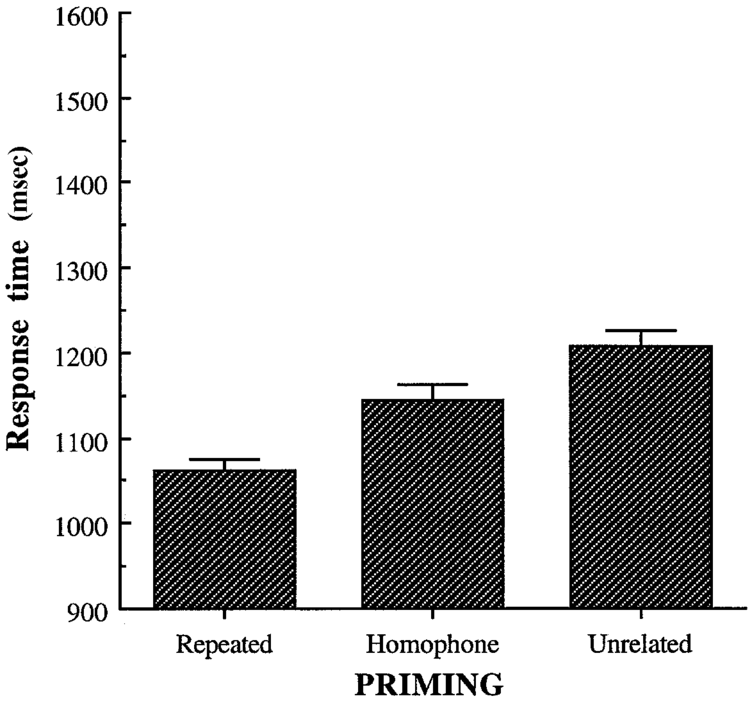

Fig. 8. Average correct RTs to targets preceded by repeated, homophone, or unrelated primes in IH (Exp. 2).

letter) may be recognised faster than words with few orthographic neighbours (Andrews, 1989, 1992; Forster & Shen, 1996; Peereman & Content, 1995; Sears, Hino, & Lupker, 1995). Although the exact cause for this facilitatory effect of increased orthographic neighbourhood size is still unclear (Forster & Shea, 1996), its occurrence is generally assumed to depend on a global (i.e. parallel) activation of orthographic word forms (Andrews, 1992; Peereman & Content, 1995; Sears et al., 1995).

In contrast, if overt word recognition was conducted by a strictly letter-by-letter procedure, as often assumed for LBL readers, one should expect the effect of increased orthographic neighbourhood size to be inhibitory. Assume, for instance, a simple word recognition model in which a letter processing module sequentially feeds information about letter identities to another module representing the orthographic forms of words. Assume also, as suggested by observations by Arguin and Bub (1995; see Luce, 1959, 1977, for a detailed discussion), that overt recognition of the target is achieved once the ratio of activation of its lexical representation (i.e. signal) over the activation of other lexical representations (i.e. noise) exceeds some fixed threshold. With every letter identity that is sequentially passed to the word-form system, the activation of the target and of any other word compatible with the

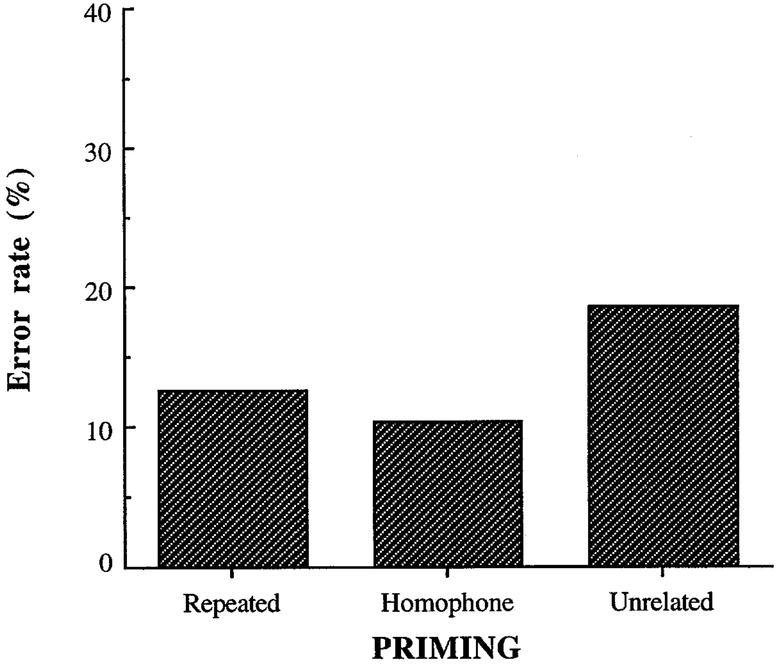

Fig. 9. Percentage error rates to targets preceded by repeated, homophone, or unrelated primes in IH (Exp. 2).

letter input received up to that point will increase to the same degree (assuming everything else is equal). Only once an incompatible letter identity is encountered will the activation of a nontarget representation begin to be lower than that of the target, and presumably this activation should decay over a period of time rather than vanish immediately. Statistically, what this means is that, with serial letter input, nontarget representations should be activated in greater numbers, to a greater degree, and for a longer duration if the target has many orthographic neighbours than if it has few or none. This increased background noise against which the activation of a target word with many orthographic neighbours must be assessed should be costly in terms of overt recognition performance. By contrast, if the letter input to the word form system is parallel, letter information incompatible with orthographic neighbours of the prime is received at the same time as compatible letter identities. This should keep the activation of orthographic neighbours of the prime sufficiently low from the outset that any noise they produce within the lexical system remains manageable and does not prevent whatever facilitatory effect these neighbours may otherwise have on target processing to be manifest in performance. Congruent with the notion that orthographic neighbours may negatively affect reading performance when incomplete letter identity information is passed to the word-form system– as it is for some duration if reading is strictly letter-by-letter– are observations from a patient with neglect dyslexia (Arguin & Bub, 1997). This patient very often tended to ignore the first letter of words in her reading attempts and her results suggest that orthographic neighbours of the target that differed from it on their first letter were strongly activated. Thus, when the target had many such neighbours that were of a higher frequency than itself, the patient's neglect error rate was doubled relative to when the target had no such neighbours.

According to the view presented here, if overt word recognition in LBL reading is exclusively mediated by sequential letter identification, performance should be negatively affected by an increase in orthographic neighbourhood size. In contrast, the observation of a facilitatory effect of increased orthographic neighbourhood size in an LBL reader would argue for a contribution of covert orthographic lexical activation (i.e. lexical access based on parallel letter processing) to overt word recognition performance. The central aim of Exp. 3 is to provide a test of these contrasting predictions.

Another factor that has been shown to affect word recognition times in neurologically intact subjects, and which may be assumed to result at least in part from the activation of the global orthographic form of the target, is lexical frequency (e.g. Monsell, Doyle, & Haggard, 1989; Paap, McDonald, Schvaneveldt, & Noel, 1987; Waters & Seidenberg, 1985). In another paper of this issue, the literature review of Behrmann et al. (this issue) shows that LBL readers also generally show benefits from increased lexical frequency, and the authors suggest that this benefit must result from a parallel input to the word-form system since it increases as a function of word length. In the present experiment, the word-frequency effect will be used not so much as a direct index for the occurrence of covert lexical activation, but rather as a way to characterise this covert activation by examining how the frequency effect interacts with orthographic neighbourhood size. Indeed, in neurologically intact observers, the facilitatory effect of increased neighbourhood size is greater with, or exclusive to, low-frequency words (Andrews, 1989, 1992; Peereman & Content, 1995; Sears et al., 1995). Inasmuch as a facilitatory effect of increased orthographic neighbourhood size may be found in an LBL reader, the interaction of this factor with lexical frequency should help characterise the mechanisms responsible for covert lexical activation.

The effect of orthographic neighbourhood size and its interaction with lexical frequency were examined here by having IH and a group of neurologically intact subjects read aloud a series of four-letter words that varied orthogonally on their numbers of orthographic neighbours and their lexical frequencies.

Methods

Subjects were IH and a group of 15 neurologically intact individuals (5 males, 10 females) aged between 18 and 20. Normal subjects served to determine that the results expected from an intact reading system actually occur under the experimental conditions used here. Each trial began with a 1500msec fixation point, displayed at the centre of the computer screen, on which subjects were instructed to keep their eyes fixated. This was followed by an upper-case word target whose right extremity was aligned 1cm (1.1°; from a viewing distance of about 50cm) to the left of fixation. The target was printed in upper case and remained visible until response, which was then typed in by the experimenter before the next trial was initiated by a keypress. The subject's task was to name the target as rapidly as possible while avoiding errors. As in previous experiments, response times were registered by a voice-key connected to the computer controlling the experiment. Target words ($N = 50$ per condition; Appendix C) varied orthogonally on their numbers of orthographic neighbours (Low range: 0–3; High range: 11 or more) and their lexical frequencies (Low range: 1–15; High range: 100 or more). Across conditions, words were matched quadruplet-wise on single-letter (average sum across words = 833.8) and bigram frequencies (average sum across words = 244.7). As in the previous experiments, words with irregular spelling-to-sound correspondences were avoided because the patient is more likely to commit naming errors with such words. Throughout the list there was a total of eight irregular words; four were low frequency/ low neighbourhood size, one low frequency/ high neighbourhood, one high frequency/ low neighbourhood and two high frequency/ high neighbourhood. To ensure enough observations per condition, the complete stimulus list was administered to IH twice in different sessions separated by an interval of 2 weeks. For IH, a total of 11 trials (2.8%) were lost due to the failure of the subject's response to trigger the microphone. Across all trials run with neurologically intact subjects, 18 trials (0.6%) were lost due to a microphone error. These trials were not considered in the data analysis.

Results

Average correct RTs and error rates for normal subjects are presented in Figs. 10 and 11, respectively. The correlation between RTs and error rates was high and positive (+ .98; $P < .05$), which indicates no speed-accuracy tradeoff. For each subject, RTs that were more than 3 SDs away from the mean for their condition were discarded. A total of 18 data points (0.6% of trials) were removed from the analysis on this criterion. An ANOVA conducted on correct RTs with Orthographic neighbourhood size and Lexical frequency as factors showed main effects of neighbourhood size [$F(1,14) = 10.6$; $P < .01$] and of frequency [$F(1,14) = 16.2$; $P < .005$], as well as a marginally significant interaction [$F(1,14) = 3.9$; $P < .07$]. The main effects indicated shorter RTs to words with many orthographic neighbours and to high-frequency words. Simple effects of neighbourhood size as a function of frequency showed a significant effect of number of neighbours with low-frequency items [$t(14) = 3.1$; $P < .01$], but none with high-frequency words [$t(14) = 1.3$; *n.s.*]. The outcome of the analysis of error rates paralleled that with RTs. Thus, main effects of neighbourhood size [$F(1,14) = 16.0$; $P < .005$]

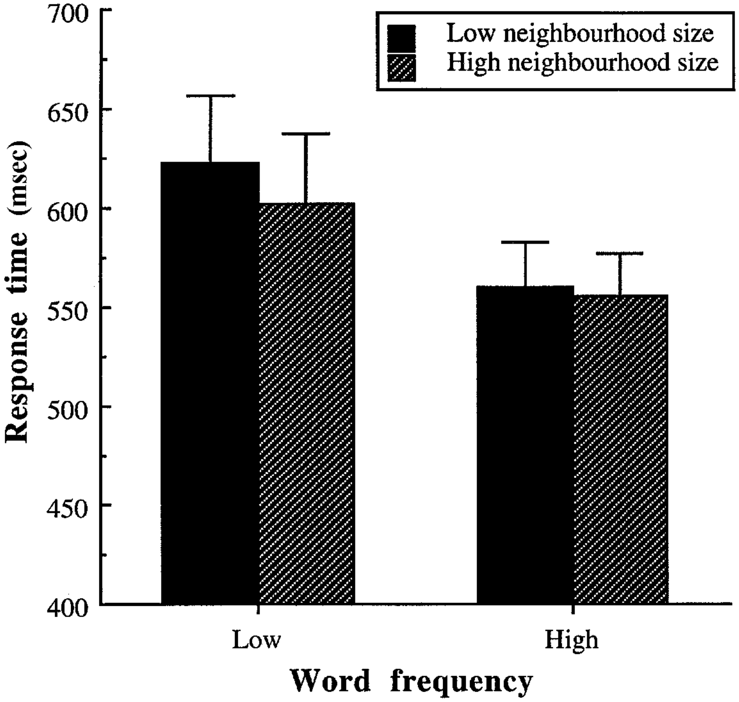

Fig. 10. Average correct RTs as a function of orthographic neighbourhood size and frequency of the target in neurologically intact subjects (Exp. 3).

and frequency [$F(1,14) = 22.1$; $P < .001$] were present, as well as a significant neighbourhood size × frequency interaction [$F(1,14) = 6.8$; $P < .05$]. Error rates were reduced with high neighbourhood size targets and with words that had a high frequency. Simple effects of the interaction showed a significant effect of neighbourhood size with low frequency words [$t(14) = 3.7$; $P < .005$] but not with high-frequency words [$t(14) = 1.2$; *n.s.*].

Average correct RTs and error rates for IH are shown in Fig. 12 and 13, respectively. The correlation between RTs and error rates was of + .95 ($P = .05$), which indicates no speed-accuracy trade-off. Response latencies that were more than 3 SDs away from the mean for their condition were discarded from the analysis of correct RTs. Seven data points were removed from the analysis on this criterion. A two-way ANOVA of Orthographic neighbourhood size × Lexical frequency showed significant main effects of neighbourhood size [$F(1,270) = 58.9$; $P < .001$] and of frequency [$F(1,270) = 9.1$; $P < .005$], but no interaction [$F(1,270) < 1$]. The main effects indicate shorter RTs with words with a large orthographic neighbourhood size and with high-frequency targets. Analysis of error rates showed a significant reduction of error rates with increased orthographic neighbourhood size [$\chi^2(1) = 16.4$; $P < .001$] but no effect of lexical frequency [$\chi^2(1) = 0.1$; *n.s*].

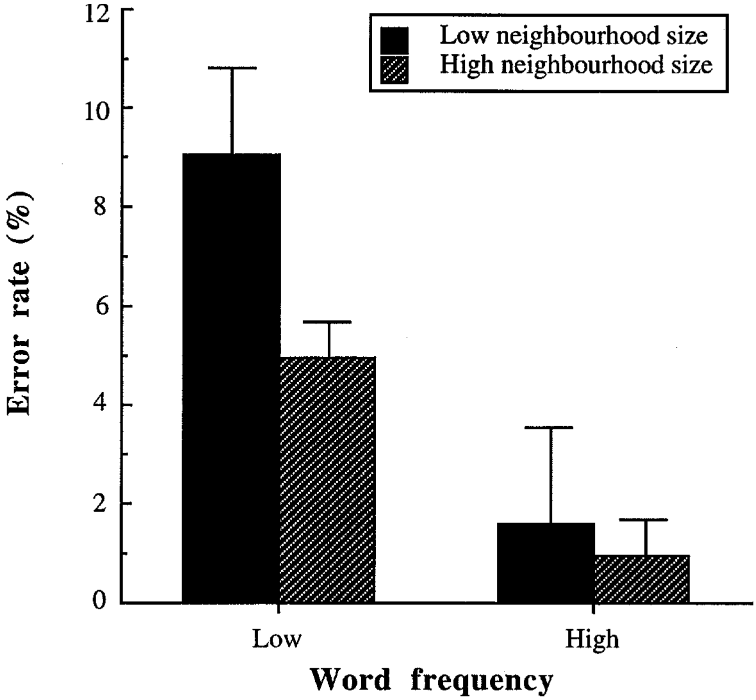

Fig. 11. Percentage error rates as a function of orthographic neighbourhood size and frequency of the target in neurologically intact subjects (Exp. 3).

Discussion

The results of Exp. 3 have shown a very substantial facilitation of overt word recognition performance in IH by an increase in the number of orthographic neighbours the target has. Thus, increased neighbourhood size led to an overall 222msec reduction in RTs and to half as many errors as with low neighbourhood size targets (Figs. 5 and 6). As discussed in the introductory section of this experiment, this effect is incongruent with the hypothesis of overt word recognition in LBL reading being mediated strictly by an LBL process. Rather, these observations point to an important contribution of covert orthographic lexical activation to overt word recognition performance. This is congruent with the word priming results previously observed in IH, whereby the prior activation of the orthographic representation of the target by the prime facilitated its overt recognition.

In contrast to priming results from IH, however, one interesting aspect of Exp. 3 is that it suggests a major discrepancy between the patient and neurologically intact observers on the activation of the orthographic forms of words. Thus, whereas IH showed significant and equal facilitation from increased orthographic neighbourhood size with low- and high-frequency words, the effect occurred only with

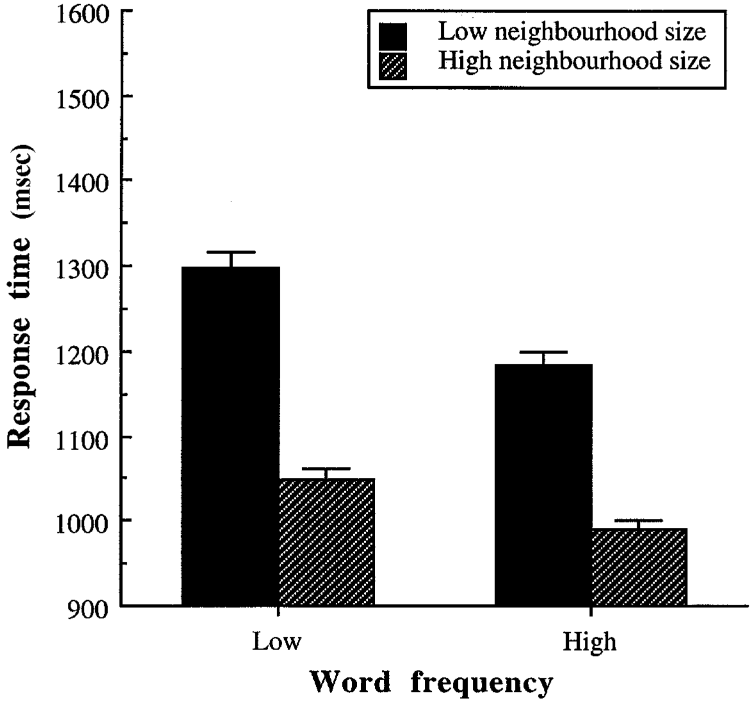

Fig. 12. Average correct RTs as a function of orthographic neighbourhood size and frequency of the target in IH (Exp. 3).

low-frequency words in normal subjects. The form of the interaction observed in normals suggests that although both increased neighbourhood size and frequency facilitate word recognition, this facilitation saturates when these two factors are combined. That is, with high-frequency words, it seems that there was no room for further performance improvement with increased neighbourhood size. No such saturation is apparent in IH's results, however, because increased orthographic neighbourhood size facilitated performance just as much with low- and high-frequency words. This lack of an interaction in IH is not simply due to insensitivity of the patient to lexical frequency, as he showed a substantial reduction of response latencies with high-frequency words[3]. Rather, it appears that, in contrast to normals, even with words of high frequency and large neighbourhood size, the activation of orthographic word forms in IH is still not optimal and that there is room for it to be improved further. This points to an anomaly in the activation of lexical representations in IH, and in particular it suggests that this

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[3] Note that this effect cannot be attributed to the frequencies of sublexical components of words because items were matched on single-letter and bigram frequencies.

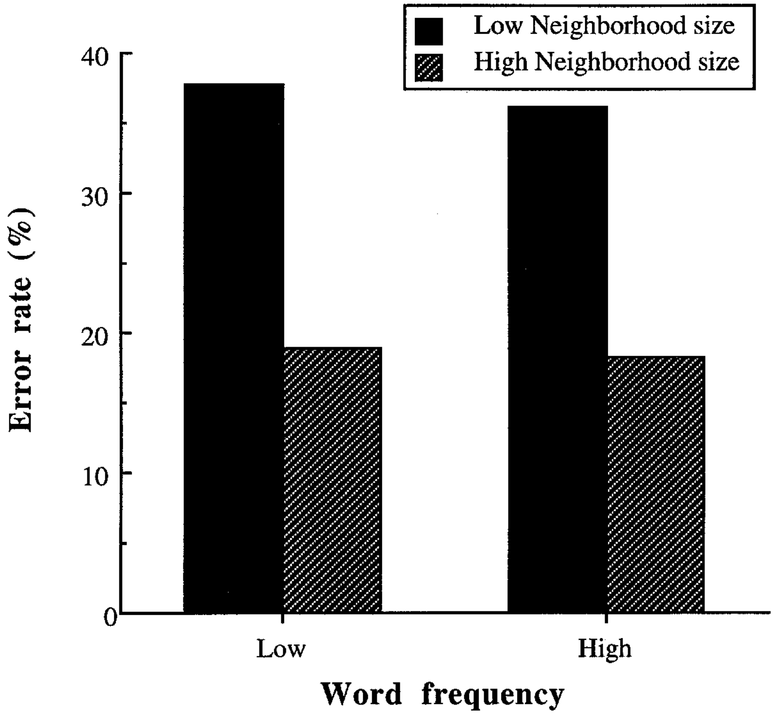

Fig. 13. Percentage error rates as a function of orthographic neighbourhood size and frequency of the target in IH (Exp. 3).

activation may be weaker than in normal readers, thus explaining the absence of a saturation effect in the patient's results in Exp. 3. This characterisation of covert lexical activation in IH implies that it may be a limitation on the activation of orthographic word forms, achieved through a parallel processing of letters, which forces the patient to rely on a serial letter identification strategy for the overt recognition of words. This view, which is similar to that proposed by other investigators to explain implicit reading in their LBL patients, is discussed in greater detail in the next section.

GENERAL DISCUSSION

The phenomenon of implicit reading in brain-damaged patients suffering from letter-by-letter reading suggests a process of covert lexical activation, whereby some form of lexical access– which fails to support overt word recognition reliably– occurs rapidly on the basis of the parallel processing of the constituent letters of the stimulus. An accurate characterisation of covert lexical activation in LBL readers through the use of implicit reading evidence has proven difficult because several patients do not show the phenomenon, which also appears sensitive to strategy effects. However, previous observations (Bowers, Arguin, et al., 1996; Bowers, Bub, et al., 1996; Howard,

1991) suggested that covert lexical activation may affect overt word recognition performance in LBL readers. On this basis, the present paper aimed to specify the extent as well as some limits of covert lexical activation in LBL dyslexia by studying the effect of variables assumed to denote such activation on the overt word recognition performance of patient IH. The variables studied here were those of masked abstract orthographic (Exp. 1) and homophone (Exp. 2) priming, as well as the effect of orthographic neighbourhood size of a target and the interaction of this factor with lexical frequency (Exp. 3).

In Exp. 1, masked identity primes printed in a case-alternated format and shown for 100msec substantially reduced IH's reading latency for upper-case words relative to unrelated primes. In addition, the magnitude of the repetition priming effect expressed in relation to overall average RTs was quite similar to that found in neurologically intact observers in that same experiment. These observations suggest that the covert lexical activation process mediating the priming effect is based on a truly abstract orthographic encoding mechanism similar to that characterising normal reading. This result also suggests that covert lexical activation may depend on the residual function of a left-hemisphere reading mechanism since it appears, according to our current knowledge, that the right cerebral hemisphere may not be capable of supporting priming under the conditions of Exp. 1. One clear limitation of covert lexical activation in IH was demonstrated in Exp. 2 by a failure of primes that were homophones to the target to affect the patient's overt word recognition performance significantly, in contrast to observations from neurologically intact observers. This suggests that no significant degree of covert phonological activation occurs in IH. In Exp. 3, results from IH as well as from normal readers showed a facilitatory effect of increased orthographic neighbourhood size on target identification, and it was argued that such an effect could not possibly occur if reading was effected exclusively through a LBL process. The covert orthographic lexical activation implied by the neighbourhood size effect in IH appears abnormal, however. Indeed, although this effect was equally strong with high- and low-frequency words in the patient, it occurred only with low-frequency words in our normal readers. It was proposed that IH's results in that experiment may best be explained by the hypothesis that only weak activation of orthographic lexical representations is achieved through a parallel processing of letters in IH, and that this may be the reason why this form of lexical activation cannot reliably support overt word recognition.

Accounts similar to that proposed here for covert lexical activation have been offered before by a number of different authors to explain evidence for implicit reading in LBL patients (Arguin & Bub, 1993; Bub & Arguin, 1995; Bub et al., 1989; Shallice & Saffran, 1986). Essentially, the notion proposed is that the lexical activation is achieved rapidly and by a parallel analysis of letters, but that this process fails to provide an activation contrast between the target and other words that is sufficient for overt recognition. The sheer presence of some degree of activity among lexical representations may be sufficient, however, to perform classification tasks such as lexical or semantic decisions. Indeed, it may be assumed that such tasks are less demanding than that of overt recognition with respect to the quality required for the internal representation of the stimulus to maintain an accurate performance. Similarly, the presence of only a weak degree of lexical activation may be sufficient to facilitate the identification of the constituent letters of words relative to those of nonwords. Exactly the same reasoning may hold with respect to covert lexical activation effects on overt word identification. Thus, even weak lexical activation may be sufficient for word recognition to be facilitated by masked priming, for instance. Also, if an increase in orthographic neighbourhood size is assumed to facilitate the activation of the target representation obtained by a parallel encoding of the letters, either directly or via a feedback facilitation of letter processing, even weak covert lexical activation may account for the neighbourhood size effect in IH.

Clearly, however, not all codes that serve for the internal representation of words may be addressed equally well by covert lexical activation. With IH, for instance, orthographic activation, although apparently weak, was sufficient to sustain abstract priming between a lower-case or a case-alternated prime and an upper-case target, as well as the orthographic neighbourhood size effect. However, in the same patient, no significant evidence for covert phonological activation could be found in the homophone priming condition. This could have little implication for semantic processing though, so a test of covert semantic activation in IH might or might not have revealed such an effect.

When proposed, the notion of weak covert lexical activation to account for implicit reading in LBL patients is often accompanied by the assumption that representations of words similar to the target may be activated to an excessive degree or that such items are insufficiently suppressed (e.g. Arguin & Bub, 1993; Shallice & Saffran, 1986). This implies that the selectivity of covert lexical activation is deficient and that overt recognition is prevented not only by the poor signal provided by the activation of the target, but also by the high degree of noise caused by the excessive activation of other words. It seems that this may not be the case for IH, however, since masked priming does not generalise to orthographic neighbours of the target (Bowers, Arguin, et al., 1996). This observation argues for the preserved selectivity of covert lexical activation in the patient.

One important implication of the findings reported here concerns the type of processing by which overt word recognition is performed in LBL readers (Hanley & Kay, 1992; Howard, 1991; Rapcsak, Rubens, & Laguna; 1990; Warrington & Shallice, 1980). Since the discovery by Déjerine (1891) that left occipital damage may cause LBL reading, it has largely been assumed that overt word recognition in these patients is exclusively mediated by the sequential recognition of individual letters, mainly on the basis that several patients overtly name individual letters before being able to recognise a target word. In more recent years, the principal evidence that has been invoked in support for the claim that reading is essentially based on sequential letter identification is that reading times in LBL patients increase linearly with the number of letters in the target. This linear effect of number of letters does indeed strongly suggest that individual letters are processed serially in the overt word-recognition performance of LBL readers. However, it appears that this is not the only mode of lexical access for LBL readers.

One indication of this was provided by the observation of implicit reading in LBL patients, which implied a lexical access based on the parallel processing of letters. This evidence, however, did not tell us whether this form of lexical access actually contributed to overt word recognition performance. Such an indication was provided later by Howard (1991), who showed that some proportion of overt word reading responses was indeed based on parallel letter processing. Again, however, the results did not indicate whether parallel lexical access had any contribution to overt reading performance when patients resorted to an LBL process for word recognition. More recently, the word priming observations of Bowers, Arguin, et al. (1996), as well as those provided in Exps. 1 and 2 of the present paper, went somewhat further in showing that parallel letter processing could significantly contribute to overt word recognition and that this contribution was not restricted to a small subset of "anomalous" trials such as those studied by Howard (1991), but rather that it occurred consistently. However, in those experiments, evidence for parallel letter encoding essentially referred to the processing of the prime, not that of the target. It thus remained possible that overt recognition of the target itself was strictly based on a serial LBL process, even through this recognition performance was facilitated by the prior parallel processing of the prime. The facilitatory neighbourhood size effect (reported in Exp. 3), though, strongly suggests that parallel letter encoding (i.e. covert lexical activation) provides a direct and consistent contribution to the overt recognition of a word. This experiment did not assess the word length effect in IH to determine that his overt recognition performance effectively involved a sequential processing of letters. However, such serial processing in IH has been documented on several previous occasions spread across a period of 5 years, during which the magnitude of the word-length effect has remained essentially unchanged. It would seem reasonable, then, to assume that overt recognition of the targets by IH in Exp. 3 involved the serial processing of individual letters. What the facilitatory effect of increased orthographic neighbourhood size in IH suggests, therefore, is that parallel and serial letter processing mechanisms may provide a conjoint contribution to overt word recognition performance in LBL reading.

Interestingly, on the basis of distinct indicators that are also different from those used in the present paper, reports by Behrmann et al. (this issue) and by Montant et al. (this issue) also argue for conjoint effects of parallel and serial letter processing on the overt word recognition performance of LBL readers. As discussed in the introduction, this conjoint contribution may result from separate serial and parallel letter processing mechanisms that converge onto a common lexical system that is directly responsible for overt word recognition. Alternatively, one may assume the operation of a single reading system in which lexical activation from the parallel processing of letters is possible, but this activation must be supplemented by the focused processing of individuals letters to render overt word recognition possible. Behrmann et al. and Montant et al. have opted for the second, more parsimonious account, since they found no indication suggesting the need to assume separate systems mediating the parallel and serial processes. However, previous observations indicating a puzzling dissociation between word and letter priming in IH suggest the possibility of separate systems mediating covert lexical activation and serial letter identification for overt word recognition.

Bowers, Arguin et al. (1996), using a priming procedure identical to that of Exp. 1 but in a task of single-letter identification, have shown a deficit in abstract letter encoding in IH (see also Arguin & Bub, 1994; for similar findings in LBL patient DM). Thus, a masked prime that is nominally identical to the target but visually different from it (e.g. a/ A) had no effect relative to an unrelated prime with a prime duration of 100msec, even though physical identity priming caused large benefits. This is markedly different from what was previously observed by Arguin and Bub (1995) in neurologically intact subjects. They showed very substantial benefits with nominally identical primes with a prime duration as short of 100msec, and these benefits did not differ from those obtained with physically identical primes. The absence of abstract letter priming in IH with 100msec primes is in striking contrast to his performance in the word priming task, which shows large benefits from abstract repetition priming with a prime duration of 100msec. This qualitative dissociation between letter and word priming in IH suggests that two separate reading mechanisms may be active in the patient. One of them, responsible for covert lexical activation effects, would be abstract with respect to visual shape. The other, serving for the overt identification of isolated letters, would be shape specific. If this latter mechanism is also responsible for the sequential processing of strings of letters in overt word recognition tasks, it would mean that the parallel and serial processes involved in such tasks are mediated by separate systems.

Such a possibility raises another crucial issue concerning efforts directed to a specification of the functional impairment(s) responsible for LBL reading. The logic commonly employed for this purpose is to attribute the high-level word recognition disorder to some demonstrated impairment of a low-level process on which it depends for normal performance, even if it is sometimes difficult to provide a clear and detailed functional account of the relation between cause and effect. In the case of IH, for instance, this logic could attribute the reading disorder to the deficit in abstract orthographic encoding suggested by the letter priming results. It seems this account may be mistaken, however, given the qualitative dissociation between word and letter priming that is shown by the patient. Rather, it appears that the letter priming results observed in IH may be relevant not so much to specify the cause of his reading disorder, but rather to characterise some compensatory process the patient must rely on for overt word recognition. What this means, then, is that caution should be exercised in assigning a causal relationship between LBL reading and other concomitant impairments, since these associated deficits may in fact reflect a form of adaptation to the reading disorder rather than its cause.

CONCLUSIONS

The investigation of covert lexical activation in LBL patient IH has shown that this process is based on an abstract orthographic encoding mechanism comparable to that mediating reading in neurologically intact observers, and that this process may depend on the residual function of the damaged left hemisphere. Two anomalies of covert lexical activation in IH were identified, however: (1) it does not extend to the activation of the phonological representations of words; and (2) orthographic activation resulting from a parallel encoding of letters may be particularly weak compared to that achieved in normal readers. The latter may be fundamental for the obligation of LBL patients to resort to serial letter processing for overt word recognition. Finally, results suggest that serial and parallel letter processing mechanisms contribute conjointly to the patient's overt word recognition performance.

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APPENDIX A

Stimulus List Used in Exp. 1

Target	Target Frequency	Repeated Prime	Unrelated Prime
ACRE	High	AcRe	BaNd
BAND	High	bAnD	gRaY
BASE	High	BaSe	tEaR
BEND	High	bEnD	dAtA
CARD	High	CaRd	hEaR
CARE	High	cArE	fEeD
DARE	High	dArE	BeNd
DARK	High	DaRk	rEaD
DATA	High	DaTa	aCrE
DEAD	High	dEaD	gAvE
DEEP	High	dEeP	HaRd
DRAW	High	dRaW	cArD
EVER	High	eVeR	DaRe
FEED	High	FeEd	MaDe
GATE	High	GaTe	DeAd
GAVE	High	GaVe	hEaD
GRAY	High	GrAy	RaCe
HARD	High	hArD	DeEp
HEAD	High	HeAd	gAtE
HEAR	High	HeAr	bAsE
HERE	High	HeRe	rOaD
MADE	High	mAdE	EvEr
NEED	High	NeEd	dArK
PAGE	High	pAgE	DrAw
RACE	High	rAcE	nEeD
RATE	High	RaTe	sEeD
READ	High	ReAd	CaRe
ROAD	High	RoAd	hErE
SEED	High	SeEd	rAtE
TEAR	High	TeAr	PaGe
BANG	Low	BaNg	wEed
BARD	Low	BaRd	dReG
BARK	Low	bArK	PeAr
BEAD	Low	BeAd	cAgE
BEAN	Low	BeAn	rApE
BREW	Low	bReW	jAdE
CAGE	Low	CaGe	bEaD
DAME	Low	DaMe	bEaN
DARN	Low	dArN	ReEk
DART	Low	dArT	rEeF
DEED	Low	dEeD	gOrE
DEEM	Low	dEeM	GaRb
DEER	Low	dEeR	wAde
DREG	Low	DrEg	sAgE
EDEN	Low	EdEn	bArD
GARB	Low	gArB	DeEd
GORE	Low	GoRe	DeEm
HEED	Low	HeEd	mArE
JADE	Low	JaDe	sEaR
MARE	Low	MaRe	ReEd
PEAR	Low	pEaR	BaRk
RAKE	Low	rAkE	eDeN
RAPE	Low	RaPe	hEeD
REED	Low	rEeD	dAmE
REEF	Low	ReEf	Dart
REEK	Low	rEeK	DaRn
SAGE	Low	SaGe	DeEr
SEAR	Low	SeAr	RaKe
WADE	Low	WaDe	BrEw
WEED	Low	WeEd	bAnG

Note that primes are each shown only under one of the versions used across repetitions of prime–targets pairs, with the other versions corresponding to an inversion of the upper- and lower-case assignments for letters in the prime.

APPENDIX B

Stimulus List Used in Exp. 2

Target	Repeated Prime	Homophone Prime	Unrelated Prime
ALTAR	altar	alter	beech
ALTER	alter	altar	creek
BAIL	bail	bale	prey
BALE	bale	bail	seem
BEACH	beach	beech	steel
BEECH	beech	beach	alter
BLEW	blew	blue	meat
BLUE	blue	blew	gait
CELL	cell	sell	pray
CREAK	creak	creek	alter
CREEK	creek	creak	steal
FEAT	feat	feet	mail
FEET	feet	feat	male
FLEA	flea	flee	pail
FLEE	flee	flea	tail
GAIT	gait	gate	blue
GATE	gate	gait	heal
HEAL	heal	heel	rain
HEEL	heel	heal	pale
MAIL	mail	male	week
MALE	male	mail	rein
MEAT	meat	meet	sale
MEET	meet	meat	sail
PAIL	pail	pale	feat
PALE	pale	pail	weak
PRAY	pray	prey	sell
PREY	prey	pray	cell
RAIN	rain	rein	tied
REIN	rein	rain	bail
ROAD	road	rode	heel
RODE	rode	road	feet
SAIL	saiL	sale	flea
SALE	sale	sail	blew
SEAM	seam	seem	tale
SEEM	seem	seam	gate
SELL	sell	cell	tide
STEAL	steal	steel	beach
STEEL	steel	steal	creak
TAIL	tail	tale	seam
TALE	tale	tail	flee
TIDE	tide	tied	meet
TIED	tied	tide	rode
WEAK	weak	week	bale
WEEK	week	weak	road

APPENDIX C

Stimulus List Used in Exp. 3

Target	Frequency	Orthographic Neighbourhood Size
ACRE	low	Low
ARCH	low	Low
BLUR	low	Low
CHAR	low	Low
CHEF	Low	Low
CYST	Low	Low
DUKE	Low	Low
EARL	Low	Low
EDEN	Low	Low
FERN	Low	Low
FETE	Low	Low
FRET	Low	Low
FROG	Low	Low
FUME	Low	Low
FUSE	Low	Low
FUSS	Low	Low
GENE	Low	Low
GLEN	Low	Low
GREY	Low	Low
HAWK	Low	Low
JADE	Low	Low
JOWL	Low	Low
KELP	Low	Low
LIED	Low	Low
LIMB	Low	Low
LISP	Low	Low
LOAF	Low	Low
NORM	Low	Low
OATS	Low	Low
OILY	Low	Low
OXEN	Low	Low
PITY	Low	Low
PONY	Low	Low
PREY	Low	Low
PROD	Low	Low
ROMP	Low	Low
ROSY	Low	Low
SEWN	Low	Low
SILO	Low	Low
THUD	Low	Low
THUG	Low	Low
TOMB	Low	Low
TROT	Low	Low
VEER	Low	Low
VOID	Low	Low
WATT	Low	Low
WEPT	Low	Low
WIRY	Low	Low
WISP	Low	Low
WITS	Low	Low
BALE	Low	High
BEAD	Low	High
BOOT	Low	High
BULL	Low	High
CAKE	Low	High
CAVE	Low	High
COKE	Low	High
CONE	Low	High
DAME	Low	High
DANE	Low	High
DENT	Low	High
DINE	Low	High
DOLE	Low	High
DUCK	Low	High
FAKE	Low	High
FOLD	Low	High
FORE	Low	High
GALE	Low	High
GALL	Low	High
GORE	Low	High
HACK	Low	High
HARE	Low	High
HEAL	Low	High
HOOT	Low	High
HOSE	Low	High
LACE	Low	High

LAME	Low	High	MUCH	High	Low
LASH	Low	High	NEWS	High	Low
LENT	Low	High	ONCE	High	Low
LICE	Low	High	ONLY	High	Low
LONE	Low	High	OPEN	High	Low
LOOT	Low	High	OVER	High	Low
LORE	Low	High	PLAN	High	Low
LUST	Low	High	PLAY	High	Low
MASH	Low	High	SIZE	High	Low
MOLE	Low	High	SUCH	High	Low
NAIL	Low	High	THEY	High	Low
PATE	Low	High	THIS	High	Low
PEAR	Low	High	THUS	High	Low
RAKE	Low	High	TOWN	High	Low
RAVE	Low	High	TRUE	High	Low
REED	Low	High	TYPE	High	Low
SAGE	Low	High	UNIT	High	Low
SEAR	Low	High	UPON	High	Low
SLOT	Low	High	USED	High	Low
TAME	Low	High	VARY	High	Low
VALE	Low	High	VIEW	High	Low
VEST	Low	High	WALK	High	Low
WALE	Low	High	WAYS	High	Low
WART	Low	High	WHAT	High	Low
ABLE	High	Low	WHEN	High	Low
ALSO	High	Low	WHOM	High	Low
AREA	High	Low	WITH	High	Low
AWAY	High	Low	WONT	High	Low
BLUE	High	Low	BACK	High	High
BODY	High	Low	BALL	High	High
BOTH	High	Low	CARE	High	High
CITY	High	Low	CASE	High	High
CLUB	High	Low	COLD	High	High
DATA	High	Low	COME	High	High
DOES	High	Low	CORE	High	High
DOWN	High	Low	DATE	High	High
EACH	High	Low	DEAL	High	High
ELSE	High	Low	DONE	High	High
EVEN	High	Low	FALL	High	High
FREE	High	Low	FEAR	High	High
FROM	High	Low	FILE	High	High
GIRL	High	Low	FINE	High	High
HIGH	High	Low	FIRE	High	High
INTO	High	Low	FULL	High	High
KEPT	High	Low	GAME	High	High
MANY	High	Low	GAVE	High	High

HARD	High	High	NEAR	High	High
HART	High	High	PAST	High	High
HAVE	High	High	RACE	High	High
HEAD	High	High	RATE	High	High
HOLD	High	High	READ	High	High
HOLE	High	High	ROLE	High	High
LACK	High	High	SALE	High	High
LAST	High	High	SAME	High	High
LATE	High	High	SENT	High	High
LEAD	High	High	TAKE	High	High
LINE	High	High	WALL	High	High
LOST	High	High	WAVE	High	High
LOVE	High	High	WENT	High	High
MAKE	High	High	WIDE	High	High
MALE	High	High	YEAR	High	High
MORE	High	High			
MUST	High	High			