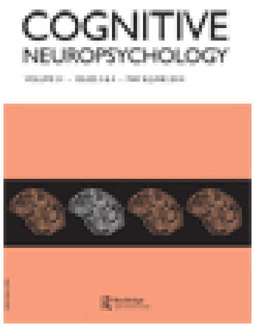

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Phonological Activation in Pure Alexia

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PHONOLOGICAL ACTIVATION IN PURE ALEXIA

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Pure alexia is a reading impairment in which patients appear to read letter-by-letter. This disorder is typically accounted for in terms of a peripheral deficit that occurs early on in the reading system, prior to the activation of orthographic word representations. The peripheral interpretation of pure alexia has recently been challenged by the phonological deficit hypothesis, which claims that a postlexical disconnection between orthographic and phonological information contributes to or is responsible for the disorder. Because this hypothesis was mainly supported by data from a single patient (IH), who also has surface dyslexia, the present study re-examined this hypothesis with another pure alexic patient (EL). In contrast to patient IH, EL did not show any evidence of a phonological deficit. Her pattern of performance in naming was not qualitatively different from that of normal readers; she appeared to be reading via a mode of processing resulting in strong serial and lexical effects, a pattern often observed in normal individuals reading unfamiliar stimuli. The present results do not obviously support the phonological hypothesis and are more consistent with peripheral interpretations of pure alexia. The peripheral and the phonological accounts of pure alexia are discussed in light of two current models of visual word recognition.

INTRODUCTION

Pure alexia and letter-by-letter reading are the terms used (often interchangeably) to define a disorder that affects reading while sparing other linguistic abilities in premorbidly literate adults. This reading deficit typically manifests after a lesion in the left occipital cortex (Damasio & Damasio, 1983; Déjèrine, 1892; Greenblatt, 1976; Henderson, 1986; see Leff et al., 2001, for functional and anatomical data showing involvement of the left occipitotemporal junction). Despite intact oral comprehension, written and oral production, these patients typically take an abnormally long time to read single words and, a fortiori, sentences (Behrmann, Shomstein, Barton, & Black, 2001). The hallmark of pure alexia is the word length effect: naming latencies increase roughly monotonically with the number of letters in a word. Unlike most other forms of acquired dyslexia, the impairment affects all types of letter strings, regardless of lexical status, grammatical class, orthographic regularity, or phonology (Mycroft, Behrmann, & Kay, 2001; Reuter-Lorenz & Brunn, 1990; Shallice & Saffran, 1986; for compatible evidence from functional imaging, see Tagamets,

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Novick, Chalmers, & Friedman, 2000, and for evidence from MEG, see Tarkianen, Helenius, Hansen, Cornelissen, & Salmelin, 1999).

Different interpretations have been proposed to account for pure alexia, mainly with respect to the functional locus of the deficit. According to the "peripheral view," the deficit occurs early on in the reading system, prior to the activation of an orthographic representation of words. On this account, this peripheral deficit disturbs either the visual stages of word processing (Behrmann, Nelson, & Sekuler, 1998a; Behrmann, Plaut, & Nelson, 1998b; Farah & Wallace, 1991; Hanley & Kay, 1992; Sekuler & Behrmann, 1996) or the letter processing stage (Arguin & Bub, 1993; Behrmann & Shallice, 1995; Bub & Arguin, 1995; Howard, 1991; Reuter-Lorenz & Brunn, 1990; Saffran & Coslett, 1998). According to the "central view," the deficit occurs at a later stage and disrupts either the computation of lexical orthographic information (Déjèrine, 1892; Patterson & Kay, 1982; Warrington & Shallice, 1980) or the computation of postlexical phonological information (Arguin, Bub, & Bowers, 1998; Bowers, Arguin, & Bub, 1996a; Bowers, Bub, & Arguin, 1996b).

Over the last few years, there has been growing consensus in support of the peripheral view (see Behrmann et al., 1998b, for review of this literature). Recently, however, there has been a series of studies which appear to be inconsistent with this perspective. Specifically, the claim has been made that letter-by-letter (LBL) reading does not arise solely from a peripheral visuo-orthographic deficit but from a deficit "in the procedure for converting orthographic to phonological knowledge" that results in "slow access to the phonological representations needed for reading" (Bowers et al., 1996a, p. 438; see also Bowers et al., 1996b). IH, the pure alexic patient tested in these studies "cannot name words quickly, or gain access to meaning quickly because orthographic codes do not interact with phonological and semantic systems in a normal fashion." (Bowers et al., 1996b, p. 561.) To account for the word length effect that characterises pure alexia, the authors postulate 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" (Bowers et al., 1996a, p. 438). More specifically, they propose that "partial orthographic/phonological disconnection leads to "messy" phonological outputs given specific orthographic access, and this phonological pattern must be "cleaned-up" before naming can be processed. As long as it is assumed that longer orthographic strings are associated with more complicated phonological patterns, then it might be expected that this 'clean-up' is more extensive for longer words, leading to longer naming times for these items" (Bowers et al., 1996b, p. 561).

The authors substantiated their claim by providing evidence that their patient IH has relatively intact orthographic skills but cannot process phonological information during reading. IH's ability to access orthographic information was supported by the finding of a variety of supposedly orthographic effects classically observed in normal readers. For example, IH exhibited a word superiority and a word frequency effect in the free-report task (Bowers et al., 1996a). That is, in a fast masked presentation procedure, words were identified more rapidly and more accurately than pseudowords (word superiority effect) and high-frequency words were identified more rapidly and more accurately than low-frequency words (frequency effect). Although one may question whether these effects must necessarily be orthographic in nature, these effects show, at least, that the reading system of the patient is partially functioning. It should be noted that pure alexic patients with demonstrable peripheral deficits can also exhibit word superiority and word frequency effects, both of which can be explained by a model in which orthographic representations are not fully derived but are supported by top-down feedback from semantic and lexical knowledge in an Interactive Activation Model (Behrmann et al., 1998b).

IH's ability to access orthographic information was more directly supported by the finding of a cross-case priming effect in a naming task (Arguin et al., 1998; Bowers et al., 1996b). That is, IH was faster when naming a target word that was preceded by a rapidly presented identical word than when it was preceded by an unrelated word. More important, this facilitatory priming effect persisted even when primes and targets differed in case, suggesting that IH was able to compute abstract orthographic information. To support the idea that IH had spared orthographic skills, Arguin et al. (1998) also reported an effect of orthographic neighbourhood size in IH. Naming was faster and more accurate for words with many orthographic neighbours (i.e., words that differ from the target word by one letter only) than for words with no or few orthographic neighbours. It should be noted, however, that IH's naming performance for both high- and low-frequency words was facilitated by the number of orthographic neighbours, in contrast to the pattern shown by controls in which the facilitation is only seen for low-frequency words. They interpret this result as indicating that IH does not have optimal orthographic activation and that there is room for improvement as evidenced by the neighbourhood effect.

What is particularly compelling about IH's performance is the dramatic impairment in phonological processing. To demonstrate this, Arguin et al. compared homophone priming (Arguin et al., 1998) and onset priming (Bowers et al., 1996b) effects in naming in IH and a group of control subjects. The homophone priming effect consists of faster and more accurate performance for words preceded by homophones (e.g., blue/BLEW) than for words preceded by unrelated primes (e.g., side/BLEW). Given that primes and targets have the same phonological (but not orthographic) form, this facilitatory effect is classically attributed to fast and automatic activation of phonological information. The onset priming effect consists of faster and more accurate performance for words or pseudowords preceded by stimuli sharing the same first letters or phoneme (so-called onset; e.g., slape/SLAND) than for words or pseudowords preceded by unrelated primes (e.g., grint/SLAND). According to Forster and Davis (1991), it is the overlap of the first phoneme that is responsible for the facilitatory effect. Because Arguin and colleagues (1998; Bowers et al., 1996b) found neither homophone priming nor onset effects in IH but obtained both in control subjects, they state that "no significant degree of covert phonological activation occurs in IH" (Arguin et al., 1998, p. 81) and that impaired access to phonology potentially contributes to pure alexia.

This contribution of a phonological impairment to pure alexia is problematic in several respects. First, a deficit in accessing phonological information typically results in a relatively greater deficit in reading nonwords compared to words (e.g., Beauvois & Dérouesne, 1979; Coltheart, 1996). To our knowledge, this pattern of performance, which is also known as phonological dyslexia, has never been reported in pure alexia. Second, it is not clear how a phonological deficit could cause the word length effect that characterises pure alexia. A late deficit in the phonological output buffer could possibly generate a word length effect but, above all, it would generate phonological errors in all circumstances, with both words and nonwords. Phonological errors are not typically observed in pure alexia. If the authors' claim is correct that the word length effect results from slower phonological clean-up for long than for short words, then pure alexic patients should exhibit small or no word length effects in a task that does not require phonological computation (e.g., the lexical decision). However, it has been shown that the word length effect in pure alexia does not generally depend on the task and length effects in lexical decision are well documented (Behrmann et al., 1998b), although see Bub and Arguin (1995) for some task differences. Another potential problem with the data supporting the phonological deficit hypothesis is that they have been obtained from a single patient, IH, who happened to be surface dyslexic (Bowers et al., 1996a). Typically, surface dyslexic patients have greater difficulties in reading words (in particular exception words) than nonwords, while phonological dyslexics show the opposite pattern with greater difficulties in reading nonwords than words. Because a phonological deficit is suspected in phonological dyslexia, it seems paradoxical that IH can have a phonological deficit while being a surface dyslexic patient. A final, more general issue is whether all patients who exhibit an effect of word length in reading should be considered to have pure alexia. Said differently, the definition of what constitutes pure alexia requires clarification.

We attempt to address these problematic issues in this paper. We tested the hypothesis of a phonological deficit in pure alexia by investigating the reading ability of the pure alexic patient EL who showed no evidence of surface dyslexia (see Case report). To this end, we replicated three of the critical experiments of Arguin and collaborators (Arguin et al., 1998; Bowers et al., 1996b). If the phonological deficit hypothesis is correct, we should obtain converging evidence when the same task and stimuli are used with a different pure alexic patient. The first experiment aimed to study the processing of orthographic information. The second and third experiments were designed to investigate the processing of phonological information. Finally, we conducted an additional fourth experiment to investigate further EL's ability to access phonological information.

CASE REPORT

A detailed case report of EL (as well as scans of her lesion) is available in other publications (Behrmann et al., 1998a; Mycroft et al., 2001). In the present article, we provide only a brief description of the patient. The reader is referred to the more detailed publication for further information.

EL is a 48-year-old right-handed native English-speaking female with a Master's degree in teaching. She was admitted to the hospital in April 1996 for right arm weakness, blurred vision, and slurred speech caused by two embolic events. A CT scan performed at the time of admission revealed a large infarction in the territory of the left posterior cerebral artery involving the left peristriate inferotemporal visual association cortex, the posterolateral temporal cortex, and the dorsal parietal cortex in the vicinity of the occipitoparietal cortex. EL does not exhibit any writing or spelling difficulties. Out of 255 pictures from Snodgrass and Vanderwart (1980), EL made three nonphonological errors (TOE → "thumb"; NAIL → "bat, no, a nail"; and JACKET → "blouse"; Behrmann et al., 1998a). Although she is not agnosic, EL performed poorly in three pencil-and-paper perceptual fluency tests (Kits of Factor-Referenced Cognitive Tests; Ekstrom, French, & Harman, 1976). In the first test where she had to find the letter "a" in a limited number of target words among distractors, EL obtained a score 2.64 *SD*s below the normal mean. In the Number Comparison subtest, where she had to compare pairs of number strings, EL scored 3.04 below the normal mean. Finally, in the identical picture task where she had to find a target picture among a series of shapes, EL scored 1.56 *SD*s below the normal mean. The existence of a perceptual deficit in EL was confirmed in a picture identification task. In this task, the ability of the patient to name pictures was affected by the structural complexity of the pictures (Behrmann et al., 1998a): Her naming performance was disproportionately slowed as a function of the visual complexity of the stimulus.

To investigate EL's phonological skills, we replicated the nonword naming task that Berndt, Haendiges, Mitchum, and Wayland (1996) used to study the severity of phonological dyslexia in aphasic patients. The stimuli were 33 nonwords with very high frequency of grapheme-phoneme correspondences (GPC) and 20 nonwords with low frequency GPC. The stimuli were presented for unlimited duration. In the study of Berndt et al. (1996), eight patients performed very poorly (less than 20% accuracy) and only four patients (with relatively intact word reading) were sensitive to the frequency of GPC. At least one-third of the errors the patients made were lexicalisations (i.e., the nonword stimulus is transformed into a word). Among the patients, the best score was 28/33 in the high-frequency GPC condition (5 errors) and 10/20 accuracy in the low-frequency GPC condition (10 errors). In the same task, EL produced a total of four errors, all low-frequency nonwords (MEQUE → menque, SITH → sich, KOGH → coach, GITH → quith). An ANOVA performed on her correct naming latencies revealed a significant effect of GPC frequency, $F(1, 43) = 48.5$, $p < .001$. These results show that, unlike phonological dyslexic patients, EL does not have any obvious problem in computing the phonological form of nonwords, even when the nonwords have low-frequency GPC.

Finally we checked for EL's speech production in nonword repetition and spontaneous speech. For nonword repetition, we used two lists of stimuli. The first list consisted of 40 monosyllabic easy nonwords ranging from 3 to 5 letters in length (Patterson, Graham, & Hodges, 1994). The second list consisted of 40 polysyllabic difficult nonwords (Gathercole, Willis, Baddeley, & Emslie, 1994). They ranged from 2 to 5 syllables and 5 to 15 letters in length. The stimuli from the two lists were tape recorded, with a 3- silence between two consecutive stimuli, and then displayed to the patient. When repeating nonwords from the first list, EL produced three errors (tolf → tof, neath → neaf, sonk → sont). With the second list, she produced six errors (pennel → kennel, perplisteronk → leblisteronk, frescovent → freshcovent, fennetiser → fenneser, pristoractional → . . . oractional, rubid → rulibt), roughly the same number as normal subjects.

To test EL's spontaneous speech, we presented her with two pictures: a scene with three children and a father playing on a beach (Queen Square Screening Test for Cognitive Deficits, 1989), and a scene of a biker in trouble on the roadside (Farah, 1990, p. 18). EL rapidly and accurately described the two pictures with no hesitation and no obvious word-finding problem. Her spontaneous speech sample is provided in Appendix A.

To assess for hemispatial neglect, EL was submitted to the Conventional Sub-Test of the Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987), which includes line bisection, line cancellation, letter cancellation, figure copying, and figure drawing tasks. The cutoff for normal performance is 129 out of a total of 146 points. EL scored 143, indicating that she has no evidence of neglect.

EL's word length effect was investigated in a naming experiment with three-, five- and seven-letter words controlled for frequency and imageability. In this study, EL showed a clear length effect of approximately 729 ms per additional letter (Behrmann et al., 1998a). In the same experiment, AS and JD, two age-, education-, sex-, and laterality-matched control subjects, showed a small length effect with an increase in latency of 9.4 ms for each additional letter. EL's exaggerated length effect was also observed in a lexical decision task (see Behrmann et al., 1998a, for further information).

To obtain a more recent estimate of EL's word length effect, we replicated the exact naming experiment described in Behrmann et al.'s study (1998a). Stimuli were 21 three-letter words, 22 five-letter words, and 21 seven-letter words controlled for frequency and imageability. A word was presented on a computer screen for an unlimited duration. The task was to pronounce each word as quickly as possible. EL made seven errors in this task. All were visual in nature and involved the last letters of the word (e.g., blank → blan; uniform → uni; job → ja). An analysis of variance (ANOVA) performed on correct reaction times (RTs) for the items with word length as the main factor revealed a significant word length effect, $F(2, 48) = 12.3$, $p < .001$. EL showed an increase of 461 ms per additional letter as determined by a regression analysis with word length set against RT (this value is entirely consistent with the 468 ms per additional letter measured by Mycroft et al., 2001, using a different stimulus set). Although EL has improved over time, she is still pure alexic and, in comparison with other pure alexic patients, falls within the moderate range (see Hanley & Kay, 1996; also Leff et al., 2001, for values of patients with hemianopic versus pure alexia). Arguin and collaborators have proposed that their phonological interpretation of pure alexia is valid for all patients showing a word length effect close to that of IH (500 ms per letter; Bowers et al., 1996b, p. 563). Therefore, with a slope close to this value, we might expect that EL behaves like IH.

To determine whether EL's pure alexia is really pure or whether it is associated with surface dyslexia, as in IH, we conducted a naming experiment using regular and irregular words varying in frequency. These 252 words, taken from Patterson and Hodges (1992), half regular and half irregular, are matched pairwise for frequency (low, medium, high), length, and initial phoneme. The apparatus and procedure were the same as those in the previous experiment. EL's mean naming latencies and percentage of errors are presented in Figure 1. An ANOVA performed on EL's naming latencies shows a main effect of frequency, $F(2, 246) = 34.1$,

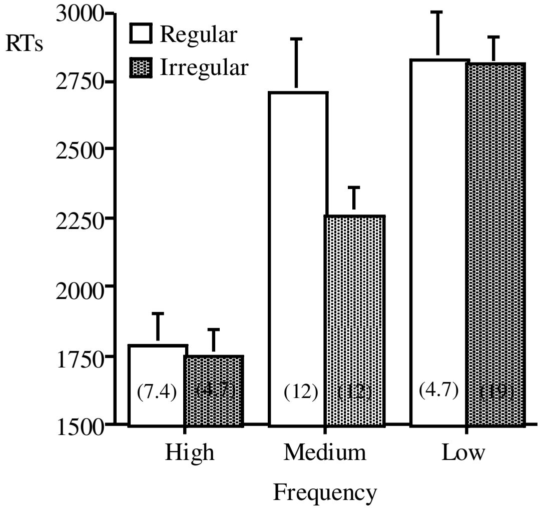

Figure 1. *Mean naming latencies and percentage of EL's naming errors (in parentheses) as a function of word frequency and regularity.*

$p < .001$, with a 1048 ms difference between high- and low-frequency items, but no main effect of regularity, $F < 1$, and no interaction between frequency and regularity, $F(2, 246) = 1.1$, $p > .1$.

Chi-square tests carried out on the error data show no significant effect of frequency nor regularity, $\chi^2(4) = 2.58$, n.s. The regularity effect remains nonsignificant, even for low-frequency words, $\chi^2(1) = 2.3$, n.s. and the frequency effect does not reach significance for irregular words, $\chi^2(2) = 4.09$, n.s. Surface dyslexia is usually characterised by a dramatic increase of naming errors for low-frequency irregular words compared to all other cells. More important, these errors are typically regularisation errors, that is, irregular words are pronounced following rules of conversion of graphemes into phonemes (e.g., the rime in PINT is pronounced as the rime in MINT). As can be seen in Figure 1, EL did not make many errors in this experiment, and read 81% of the low-frequency irregular words correctly. Moreover, EL's naming errors were mainly visual errors (i.e., breast → bree; soup → sour; dost → dose; sieve → see) involving the last letters of the words. EL made only four regularisation errors (i.e., leapt → leap, spread → gread, suite → sue it, and threat → treat), all of which might be construed as visual errors as well. The results of this experiment show that, in contrast with IH, EL is not a surface dyslexic patient.

EXPERIMENT 1

To investigate EL's ability to access orthographic information, we first replicated the experiment in which Arguin et al. (1998) manipulated the size of orthographic neighbourhood across words. In normal readers, single word naming is faster for stimuli that are orthographically similar to many other words (Andrews, 1989, 1992; McCann & Besner, 1987; Peereman & Content, 1995)[1]. An orthographic interpretation of this effect was put forward by Andrews (1989, 1992) within the framework of the interactive activation model (IAM) of McClelland and Rumelhart. According to this interpretation, a target word will activate neighbouring word nodes in the lexicon. This additional activation reverberates to the letter nodes through feedback connections, which, in turn, facilitate the processing of letters belonging to the target word. In other words, the more neighbours, the greater the support for the letters of the target word and the faster the lexical access. Indeed, IH showed a significant advantage for items with many neighbours (high-density neighbourhood) over those with few neighbours (low density neighbourhood). Facilitation was also observed for high-frequency compared to low-frequency words. Typically, the neighbourhood size effect is bigger for low-frequency words than for high-frequency words, but this was not the case in the study of Arguin et al. (1998). The interaction between neighbourhood size and frequency was not significant for IH and marginally significant for the control subjects. For a better comparison with our study, Table 1 gives the magnitude of the neighbourhood size effect and the

[1] There is a controversy in the literature about the actual effect of neighbourhood size in the lexical decision task and in the naming task using the priming paradigm (for a recent review, see Pollatsek, Perea, & Binder, 1999). But there is no controversy about the effect of neighbourhood size in the naming task *without priming*: N is always facilitatory.

Table 1. *Magnitude of the effect of neighbourhood size and the effect of frequency in IH and 15 control subjects (from Arguin et al., 1998)*

	IH		*Control subjects*	
	Neighb.	*Freq.*	*Neighb.*	*Freq.*
RTs	222 ms (18%)	87 ms (7.4%)	12 ms (2.1%)	54 ms (8.9%)
% errors	18.5	1.5	5.0	11.0

Neighb: effect of neighbourhood size; Freq: effect of frequency.

frequency effect shown by IH and his control subjects. It is also of note that IH's neighbourhood size effect is 8.5 times bigger than that of the control subjects.

We replicated this experiment with EL and two control subjects—AS and NG—matched to EL on age, sex, education, and laterality.

Apparatus

Stimuli were presented on the computer screen of a 540C Macintosh Powerbook computer controlled by PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). Stimuli were displayed in capital letters, in a 24-point Courier font. A four-letter string subtended .57 degrees of visual angle vertically and 2.09 degrees horizontally. A voice key interfaced with PsyScope was used to measure vocal reaction times (RTs). The onset of each trial was triggered manually with a button box.

Materials

The 200 four-letter words used by Arguin et al. in Experiment 3 served as stimuli. Words were varied orthogonally on orthographic neighbourhood size and lexical frequency. Neighbourhood size was measured according to the classic neighbourhood metric (N; Coltheart, Davelaar, Jonasson, & Besner, 1977). which reflects the number of words that can be obtained by changing a single letter from the target word (e.g., the word GREEN has the three neighbours GREED, GREET, and PREEN). Because, in the original description of this experiment, the exact values of the neighbourhood sizes and word frequencies are not provided, we recalculated this using the data obtained from CELEX, a computerised lexical database for English (Baayen, Piepenbrock, & Van Rijn, 1993). On our counts, high-density words had 11 to 24 neighbours (mean 16), low-density words had 0 to 17 neighbours (mean 4). High-frequency words ranged from 1 to 7424 occurrences per million (mean 609) and low-frequency words ranged from 0 to 41 occurrences per million (mean 6). Given that there is some overlap between the categories on our ratings, we assume that Arguin and colleagues used a database other than CELEX from which to derive their statistics. All stimuli are listed in Appendix B.

Procedure and design

A fixation point appeared in the centre of the screen for 1500 ms. At the offset of the fixation point, a word appeared and remained on the screen until the subject's response. The subject was required to read aloud the word as quickly and accurately as possible. Both speed and accuracy were measured. Naming latencies were registered by the voice-key. The experimenter registered the response and triggered the next trial. The 200 stimuli of the experiment were randomised and distributed over two blocks of 100 trials each. In order to increase the number of observations, EL performed the experiment twice, as did IH, with an interval of 1 week between the two sessions. The blocks were presented in a different order for the two sessions. The control subjects AS and NG performed the experiment only once. For AS, the blocks were presented in the same order as EL's session 1; for NG, the blocks were presented in the same order as EL's session 2. Before each session, the patient and the control subjects received practice with a list of 20 five-letter words that were different from the test words.

Results

For the control subjects, latencies 2 *SD*s above their condition means were removed from the analyses (5.5% of the data). For EL, we did not remove the outliers but we reduced the variance of her naming latencies using a reciprocal transformation (Y' = 1/Y, Kirk, 1982). Voice key problems caused the removal of 1.75 % of EL's data and another 3.75% of the normal participants' data. Mean correct naming latencies and percentage of errors for EL and the control subjects are provided in Figure 2. As can be seen in Figure 2, EL's naming latencies were two to four times longer than those of the control subjects.

Correct transformed RTs of EL and correct RTs of the control subjects were submitted to separated item ANOVAs with session (for EL), participant (for the control subjects), neighbourhood size, and frequency as main factors. The analysis carried out on the RTs of the control subjects revealed a significant effect of participant, $F(1, 392) = 828.3$, $p < .001$, but this factor did not interact with frequency, $F(1, 392) = 1.2$, $p > .1$, nor with neighbourhood size, $F < 1$, $p > .1$. More important, the analyses showed that high-frequency words were named significantly faster than low-frequency words, $F(1, 392) = 5.8$, $p < .05$. The size of the frequency effect is 2.33% (13 ms) for the control subjects. This value is almost identical to that obtained Arguin et al. (1998) for control subjects (12 ms, 2.11%). Naming latencies for high-density neighbourhood words did not differ significantly from naming latencies for low-density neighbourhood words, $F(1, 392) = 2$, $p > .1$. However, as can be seen in Figure 2, neighbourhood size and word frequency interacted, $F(1, 392) = 9.9$, $p < .01$: A neighbourhood size effect is observed for low-frequency words but not for high-frequency words. Contrast analyses carried out on the RTs of control subjects showed that the neighbourhood size effect was significant for low-frequency words, $F(1, 392) = 10.4$, $p < .01$, but not for high-frequency words, $F(1, 392) = 1.5$, $p > .1$. The size of the orthographic neighbourhood effect for low-frequency words is 4.32% (24 ms). Note that the magnitude of the orthographic neighbourhood effect for the control subjects in Arguin et al. (1998) is almost identical in absolute RTs (21 ms) if not in percentage (3.37%).

The ANOVA carried out on the transformed naming latencies of EL revealed a significant effect of session, $F(1, 392) = 85.7$, $p < .001$ but this effect did not interact with frequency nor with neighbourhood size (both $F < 1$). Similarly to control subjects, EL named high-frequency words significantly faster than low-frequency words, $F(1, 392) = 63.5$, $p < .001$. The size of EL's frequency effect is 25.14% (460 ms). Again, as for control subjects, EL showed no significant effect of neighbourhood size, $F < 1$ but a significant interaction between word frequency and neighbourhood size, $F(1, 392) = 6.18$, $p < .05$.

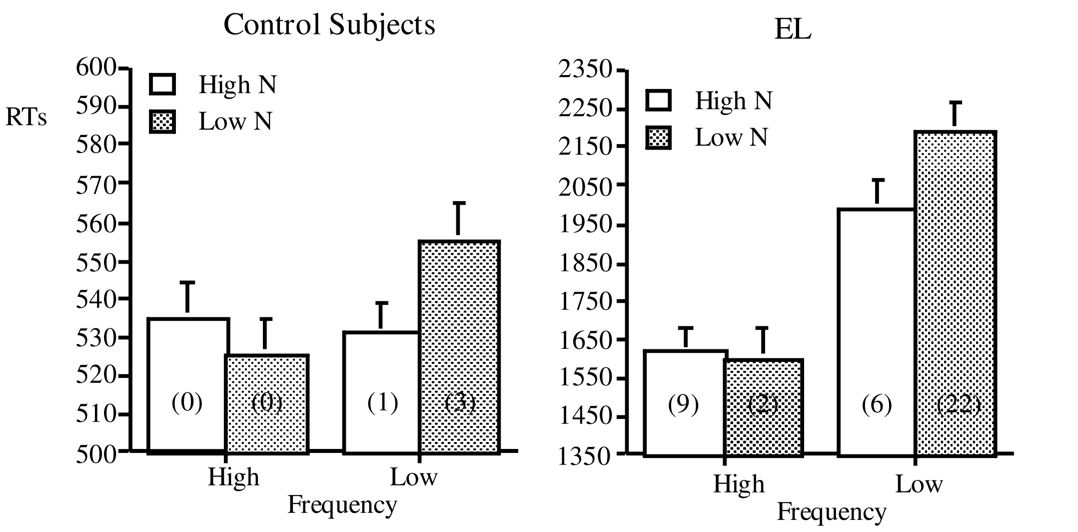

Figure 2. *Mean correct naming latencies and percentage of errors (in parentheses) for the control subjects (left panel) and EL (right panel), together with standard errors, as a function of word frequency and neighbourhood size. Note the difference of scale of the y-axes in the two panels.*

Contrast analyses revealed that the effect of neighbourhood size was significant for low frequency words, $F(1, 392) = 5.47, p < .05$, but not for high frequency words, $F(1, 392) = 1.38, p > .2$. The magnitude of her orthographic neighbourhood size effect is 13.2% (260 ms) for low-frequency words.

The number of errors in control subjects' data was not sufficient for error analyses. Chi-square tests carried out on EL's naming errors revealed a significant interaction between word frequency and neighbourhood size, $\chi^2(1) = 12.17$. Individual chi-square tests (Lancaster and Irwin method for partitioning r × c tables; Everitt, 1972) showed that the frequency effect is significant, $\chi^2(1) = 8.4$, while the effect of neighbourhood size is not significant, $\chi^2(1) = 2.3$). The magnitude of the frequency effect is 17%. For low-frequency words, the effect of neighbourhood size is significant, $\chi^2(1) = 10.63$. The magnitude of the neighbourhood size effect is 16% for low-frequency words.

Discussion

The results of Experiment 1 show that EL behaves qualitatively like normal participants when word frequency and orthographic neighbourhood size are manipulated orthogonally in a naming experiment. Like normal subjects, the patient exhibits a clear effect of frequency and an effect of neighbourhood size for low-frequency words. This pattern of results mirrors what has been found in several studies with normal adult readers (e.g., Andrews, 1989, 1992). Given that the behaviours of IH and EL are qualitatively similar to each other and to those of the control subjects, we agree with Arguin and colleagues that the processes responsible for the facilitatory effect of neighbourhood size and word frequency seem to be relatively spared in the patients. The findings from both studies are also consistent in that the patients show an orthographic neighbourhood size effect that is 3 to 4 times bigger than for the control subjects, and the frequency effect is almost 10 times bigger for EL than for the control subjects (see General Discussion for further discussion of this issue).

Arguin and colleagues have interpreted the facilitatory effect of neighbourhood size as suggesting that processing of orthographic information is not dramatically impaired in pure alexia. Although we replicate the findings of Arguin et al., we question whether this effect is purely orthographic in nature. A facilitatory neighbourhood size effect can arise at various levels. Words with many orthographic neighbours tend to have more frequent spelling-to-sound correspondences and could thus be read more quickly via sublexical phonological mechanisms than words with only a few neighbours. Similarly, high-frequency words and words with many neighbours may have more easily accessible articulatory motor programmes and may thus benefit from postlexical phonological facilitation. Alternatively, words with many neighbours may have more body/rime neighbours, which may disambiguate the pronunciation of the vowel in the target word (Andrews, 1997; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). Indeed, in a recent study by Peereman and Content (1997) it was shown that neighbourhood size is facilitatory only if orthographic neighbours are also phonological neighbours. Even if the effects observed with EL in Experiment 1 are not purely orthographic in nature, the results of this experiment show that the patient behaves essentially like normal participants except for the overall increase in naming latencies and the exaggerated lexical effects (neighbourhood size and word frequency).

It should be noted that the observation of higher-order lexical effects is not uncommon in pure alexia and is not problematic for the peripheral account of this syndrome. In a recent review of 57 cases, Behrmann and collaborators (1998b) have shown that most pure alexic patients show a word frequency effect and a word superiority effect. To the extent that the peripheral deficit does not preclude lexical access, higher-order effects can result from partial lexical activation (see Behrmann et al., 1998b), which is consistent with Andrews' (1989, 1992) account of the neighbourhood size effect.

EXPERIMENT 2

Having obtained evidence of relatively (although not perfectly) intact orthographic processing in IH, Arguin and colleagues (1998) investigated the patient's capacity to make use of whole-word phonological information. They argued that if the patient had a disconnection between the orthographic lexicon and the phonological lexicon, he should show no phonological effect in the naming task. The authors tested this hypothesis by looking for the homophone priming effect. In normal readers, this effect reflects the finding that performance for target words preceded by phonologically identical primes (homophones, e.g., week/WEAK) is better than when words are preceded by unrelated primes. The homophone priming effect has been observed in a naming task (e.g., Lukatela & Turvey, 1994a, b), a word identification task (e.g., Grainger & Ferrand, 1994; Humphreys, Evett, & Taylor, 1982), and a lexical decision task (e.g., Grainger & Ferrand, 1994). Because in most experiments, the homophone priming effect is obtained using brief exposure durations for the prime and a poststimulus mask, this effect is classically attributed to fast and automatic encoding of the phonological information conveyed by the prime. If IH was not able to access phonological information, he should not show a homophone priming effect.

Arguin and colleagues tested this prediction in a naming task with IH and 15 control subjects aged between 18 and 20. In their experiment, primes were either identical to the target word (identity priming; e.g., week/WEEK), homophonically related to the target (homophone priming; e.g., weak/WEEK), or unrelated to the target (unrelated priming; e.g., road/WEEK). As expected, the control subjects showed both identity and homophone priming effects of 52 ms (9.0%) and 44 ms (7.6%) on naming latencies, respectively. These effects did not reach significance in the error data. Like the normal subjects, IH showed a facilitation of 147 ms (12.2%) on naming latencies for identical primes. But, in contrast to normal subjects, he showed no significant homophone priming effect. Note, however, that a numerical trend appears to exist: naming latencies were 63 ms shorter (5.2%) and the percentage of errors was 9% lower in the homophone priming condition compared to the unrelated condition, although these differences did not reach statistical significance. From these results, the authors concluded that IH had relatively normal access to orthographic information (because of the identity priming effect) but his access to phonological information (because of the absence of a statistically significant homophone priming effect) was dramatically impaired, compared with the control subjects. We replicated this experiment with EL and the two control subjects, AS and NG. If EL is able to compute whole-word phonology, then she should show a homophone priming effect.

Apparatus

The apparatus of Experiment 2 is identical to that of Experiment 1. Primes were displayed as lowercase letters whereas targets were displayed as capital letters.

Materials

The stimuli used in the present experiment are identical to those of Experiment 2 in Arguin et al. (1998). Forty-four 4- and 5-letter words served as target words. Their frequency of occurrence ranged between 1 and 887 per million (mean frequency 71.6) according to the CELEX word frequency count (Baayen et al., 1993). Each target word was tested under three priming conditions: identity, homophone, and unrelated. Therefore, there were 44 target words per priming condition. The prime of each pair was used as a target in another pair. To avoid the possibility that the priming may arise from the repetition of low-level perceptual information, targets and primes contained at least two letters judged to be visually dissimilar in their upper- and lower-case format (e.g., a/A, b/B, e/E, g/G; Boles & Clifford, 1989). All stimuli are listed in Appendix C.

Procedure and design

A four-field presentation procedure was used consisting of mask-prime-mask-target. This procedure renders orthographic persistence nonspecific (Lukatela, 1996; Lukatela & Turvey, 1994b) because the mask inserted between the prime and the target reduces the possibility that the specific orthographic processing units encoding the prime are still active during the encoding of the target. Therefore, the benefits of phonological commonalties are more apparent. A mask (⊠⊠⊠⊠) was presented for 500 ms at the centre of the screen. It was then replaced by a prime which remained on the screen for 100 ms. At the offset of the prime, the mask was presented again for 33 ms. It was then immediately replaced by the probe which remained on the screen until the subject's response. The subject was required to read aloud the target as quickly and accurately as possible. Both speed and accuracy were measured. The next trial was triggered by the experimenter.

Each target word was presented three times during a session of the experiment, once in each priming condition. The 132 trials of the experiment were distributed over three blocks of 44 trials each. Within each block, the three priming conditions were randomised and each target word was presented only once. To increase the number of observations, EL completed the experiment twice, like IH, with an interval of 1 week between sessions. The blocks were presented in a different order for the two sessions. The control subjects, AS and NG, performed the experiment only once; they were tested with a 27 ms display duration for the prime because with longer duration they were able to identify the prime. In the study of Arguin et al., the prime was presented for 100 ms for the control subjects as well as for IH. The order of the blocks for AS and NG was identical to those of the two sessions for EL. Before each session, the patient and the control subjects received practice with a list of 10 prime/target pairs that were different from the test stimuli.

Results

For the control subjects, latencies exceeding 2 *SD*s from the condition means were removed from the analyses (3.41% of the data). Voice key problems caused the removal of 6.44% of EL's data and another 3.41% of the control data. Mean correct RTs and percentage of errors of the patient and the control subjects in each priming condition are presented in Table 2. Figure 3 gives the percentage of net priming in the identity and homophone priming conditions for EL and the control subjects. Net priming was calculated by subtracting the naming latencies obtained in identity and homophone priming conditions from the naming latencies obtained in the unrelated priming condition. The result of the subtraction is converted into percentage of facilitation or inhibition (relative to the naming latencies in the unrelated priming condition) to make it possible to compare directly the facilitation/inhibition observed for EL with that obtained for the control subjects.

As in Experiment 1, in the present experiment we stabilised the variance of EL's naming latencies

Table 2. *Mean naming latencies and percentage of errors for the control subjects and EL in the three priming conditions (identity, homophone, unrelated). Standard errors for RTs are given in parentheses*

	Priming condition	*Control subjects*	*EL*
Mean naming latencies	Identity	578 (9)	1286 (43)
	Homophone	576 (10)	1510 (62)
	Unrelated	636 (12)	1856 (78)
% of errors	Identity	0	4.54
	Homophone	0	5.68
	Unrelated	1.34	5.68

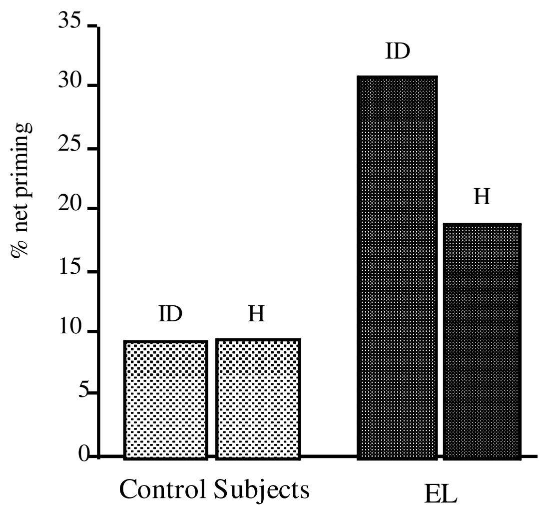

Figure 3. *Percentage of net priming for the control subjects and EL in the identity (ID) and homophone (H) priming conditions.*

by using a reciprocal transformation (Y' = 1/Y, Kirk, 1982). Correct transformed RTs for EL and correct RTs of the control subjects were submitted to separate item ANOVAs with session (for EL), participant (for the control subjects), and priming conditions as main factors. The ANOVA carried out on the control subjects' naming latencies showed that the effect of participant was significant, $F(1, 258) = 197.2$, $p < .001$, but this effect did not interact with priming condition, $F(2, 258) = 2.59$, $p > .05$. More important, the ANOVA revealed a significant effect of priming, $F(2, 258) = 18.4$, $p < .001$. The subjects' naming latencies were shorter for words preceded by identical primes or homophonic primes than for words preceded by unrelated primes, $F(1, 258) = 26.5$, $p < .001$, and $F(1, 258) = 28.6$, $F < .001$, for identity and homophone priming respectively. RTs measured in the identity priming condition did not differ significantly from RTs measured in the homophone priming condition, $F(1, 258) < 1$, $p > .5$. The magnitude of the net priming effect was 58 ms (9.12%) and 60 ms (9.43%) for identity and homophone priming, respectively, very similar to the control values obtained by Arguin et al. (1998).

The ANOVA carried out on EL's transformed RTs revealed a significant effect of session, $F(1, 258) = 16.14$, $p < .001$, but this did not interact with priming, $F(2, 258) = 1.78$, $p > .15$. More important, the patient showed a main effect of priming, $F(2, 258) = 17.90$, $p < .001$. Contrasts analyses revealed that EL's naming latencies were significantly shorter when words were preceded by identical, $F(1, 258) = 35.28$, $p < .001$, and homophonic, $F(1, 258) = 12.88$, $p < .001$, primes than by unrelated primes. EL's naming latencies were significantly shorter in the identity priming condition than in the homophone priming condition, $F(1, 258) = 5.53$, $p < .05$. The magnitude of net priming in the identity and homophone priming conditions, compared to the unrelated condition, was 570 ms (30.7%) and 346 ms (18.6%), respectively. Note that, even in percentage, these magnitudes are two to three times the size of the effects observed for the control subjects. There were too few errors in this experiment for statistical analyses (see Table 2).

Discussion

The major outcome of Experiment 2 was that, in contrast with IH, EL as well as the control subjects, showed evidence of homophone facilitation in the naming task using the fast masked priming paradigm. This suggests that EL has no obvious phonological deficit. This conclusion should be modulated, however, because in the absence of an orthographic control condition (e.g., weld/WEEK), it might well be that the facilitation obtained with homophone primes is not due to the perfect phonological overlap between primes and targets but to the overlap of the onset, or simply to the letters that primes and targets have in common. Given that EL showed more facilitation with identity primes than with homophone primes, it could be that the onset (or the first two letters) underlies the homophone priming effect while the additional facilitation of identity priming is due to the following shared letters or to the perfect overlap between identity primes and targets.

Another possibility is that EL showed a genuine homophone priming effect but that facilitation with homophone primes is less strong than facilitation with identity primes because of the particular SOA that we chose. In normal subjects, like in our control subjects, identity and homophone primes produce the same amount of facilitation (Lukatela & Turvey, 1994a, b), which suggests that phonological activation produces maximal facilitation in the naming task, and orthographic activation cannot further increase this facilitation. In Lukatela and Turvey's study (1994b), however, this pattern of similar activation varied with the SOA. Homophone and identity primes were equally efficient with a 50 ms SOA (note that we used a 60 ms SOA for control subjects) but with a 250 ms SOA, homophone primes were less efficient than identity primes. Therefore, the 133 ms SOA we used for EL could be responsible for the weaker facilitation observed with homophone primes compared with identity primes. An incremental priming study would be necessary to test this hypothesis.

As a conclusion, the results of Experiment 2 do not tell us whether EL is able to access whole-word phonology or not, but they do show that, in contrast to IH, EL obtains facilitation with homophone primes. This facilitation could be due to subword overlap between primes and targets. If this was the case, it would mean that priming is mainly sublexical in EL. In Experiments 3 and 4, we investigate EL's ability to access subword or sublexical phonology. In particular, we try to determine how much information EL is able to extract from the prime.

EXPERIMENT 3

To investigate EL's ability to access *sublexical* phonology, we replicated another experiment of Arguin and colleagues (Bowers et al., 1996b). This experiment consisted of a naming task using pseudowords and the four-field priming procedure. Primes were either identical to the targets, form-similar, or unrelated. Form-similar primes differed from the targets by only one letter, the last one in the string (for example, jear/JEAL). Bowers and collaborators designed this experiment to show that IH is able to access sublexical orthographic information but is unable to access sublexical phonological information. According to them, identity priming in pseudoword naming is due to the computation of sublexical orthography whereas form-similar priming, is similar to onset priming, which is due to the computation of sublexical phonology. If IH has a deficit in processing phonological information, he should show facilitation for identity priming but not for form-similar priming. In contrast, control subjects should show facilitation in both conditions. The results of IH and the control subjects (three undergraduate students) confirmed their prediction. IH was faster at naming target pseudowords preceded by identical primes than by unrelated primes but, in contrast to normal subjects, he was not faster at naming target pseudowords preceded by form-similar primes than by unrelated primes. There was no effect on errors. The magnitude of the identity priming effect was about 111 ms (7.6%) for IH and 68 ms for the control subjects (the percentage of facilitation is not available). The magnitude of the form-similar priming effect was about 26 ms (2.2%) for IH (nonsignificant) and 34 ms (the percentage facilitation is not available) for the control subjects.

Our understanding of this study is slightly different from that of Bowers et al. (1996b). First, given that pseudowords have no lexical representation, naming pseudowords necessarily requires the computation of some form of sublexical phonology. If a pure alexic patient shows facilitation using pseudowords in the fast masked priming paradigm, then we cannot conclude that the patient has difficulties in computing sublexical phonology. Second, we are not convinced that identity priming in this experiment reveals sublexical orthographic processing while form-similar priming reveals sublexical phonological processing. Orthographic and phonological information are difficult to dissociate in this case (and also in the case of onset priming) and are probably both involved in these priming effects. The prediction we can make from this design, however, is that if EL's sublexical processing is slow, it is likely that she might not be able to activate the final letter of the prime before the prime disappears. In this case, identity primes should not necessarily produce greater facilitation than form-similar primes as they only differ in the last letter.

In the present study, EL as well as the control subjects JD and QK participated in the experiment. JD and QK are matched with EL on sex, age, laterality and education. Our experimental conditions were identical to those of Bowers et al.'s study, except when mentioned.

Apparatus

In Bowers et al.'s study, stimuli were displayed in 24-point Geneva font. In the present study, stimuli were displayed in 24-point Courier font to ensure constant stimulus size across all priming conditions. Other display conditions are identical to those of the previous experiment.

Materials

Sixty orthographically legal four-letter pseudowords served as target stimuli. Thirty of these stimuli were presented in the identity priming condition and 30 in the form-similar priming condition. In the identity priming condition (ID), primes were identical to targets, excepted for case format (e.g., lart/LART). In the form-similar priming condition (FS), primes were identical to targets, excepted for the fourth letter and case format (e.g., jear/JEAL). An unrelated priming condition (UR1) using the same targets but unrelated primes served as baseline for ID and another unrelated condition (UR2) using the same targets and another set of unrelated primes served as baseline for FS. The list of prime stimuli used for the unrelated conditions is not provided in Bowers et al.'s paper. In the present study, targets of FS served as primes for UR1 (e.g., jeal/LART) and targets of ID served as primes for UR2 (e.g., lart/JEAL). We avoided pairing prime and target stimuli having a common letter at the same position. All target stimuli contained at least three letters with different shapes between upper- and lower-case formats. Neighbourhood size and neighbourhood frequency were balanced across conditions. All stimuli are listed in Appendix D.

Procedure and design

The procedure of Experiment 3 was identical to that of Experiment 2. In order to increase the number of observations, EL performed the experiment four times, like IH in Bowers et al.'s study. JD and QK did the experiment twice each. The stimuli were pseudorandomised so as to avoid the successive presentation of identical targets or targets with the same onset. They were presented in one single block with a break halfway through the experiment.

Results

For the control subjects, latencies above 2 *SD*s from the mean of their condition were removed from the analyses (3.75% for JD, 3.75% for QK). As in the previous experiments, we reduced the variance of EL's naming latencies by using a reciprocal transformation (Y' = 1/Y, Kirk, 1982). Voice key problems caused the removal of another 4.16% of JD's data, and 1.67% of EL's data. There was no voice key error for QK. Mean correct naming latencies and percentage of errors for JD, QK, and EL in the different priming conditions are provided in Table 3. Figure 4 gives the percentage of net priming for EL and the control subjects in the identity and form-similar priming conditions. Net priming was calculated by subtracting the naming latencies obtained in the identity and form-similar priming conditions from the naming latencies obtained in their respective unrelated conditions (UR1 and UR2).

Correct RTs of the control subjects and correct transformed RTs of EL were submitted to separate item ANOVAs with participant (for the control subjects), session, and priming condition as the main factors. For the control subjects, there was a significant effect of session, $F(1, 464) = 30.52$, $p < .001$, and a significant effect of participant, $F(1, 464) = 24.97$, $p < .001$, but none of them interacted with priming, both *F*s < 1. EL showed a significant effect of session, $F(3, 464) = 3.2$, $p < .05$, and no interaction between session and priming, $F < 1$. More important, both the control subjects and EL showed a statistically significant effect of priming, $F(3, 464) = 12.13$, $p < .001$, and, $F(3, 464) = 4.23$, $p < .01$, respectively. For the control subjects as well as for EL, latencies in the identity priming condition were shorter than latencies in UR1, $F(1, 464) = 12.69$, $p < .001$, and $F(1, 464) = 3.00$, $p = .087$, respectively, and latencies in the form-similar condition were significantly shorter than latencies in UR2, $F(1, 464) = 20.47$, $p < .001$, and, $F(1, 464) = 7.9$, $p < .01$, respectively. Compared to the unrelated conditions, the magnitude of the facilitation for the control subjects was 36 ms (5.5%) for identity priming and 46 ms (6.8%) for form-similar

Table 3. *Mean naming latencies and percentage of errors for JD and EL as a function of priming condition (standard errors for RTs are given in parentheses)*

	Priming Condition	*JD*	*EL*
Naming latencies	Identity	592 (9)	2365 (83)
	Form-similar	604 (11)	2248 (69)
	Unrelated 1	637 (12)	2594 (100)
	Unrelated 2	654 (17)	2474 (64)
% of errors	Identity	0	21.67
	FS	0	15.00
	Unrelated 1	0	11.67
	Unrelated 2	0	16.67

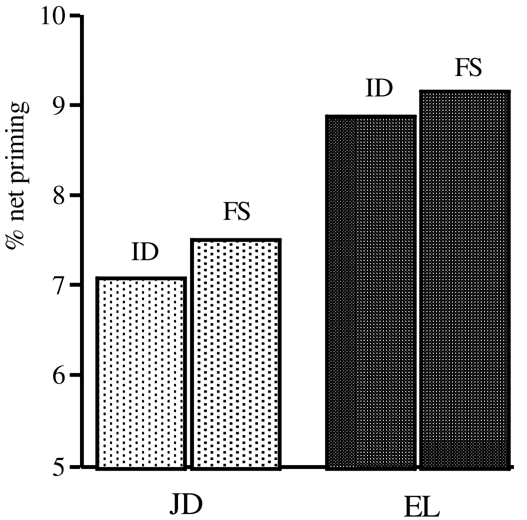

Figure 4. *Percentage of net priming for JD and EL in the identity (ID) and form-similar (FS) priming conditions.*

priming. EL exhibited a 147 ms (5.6%) facilitation in the identity priming condition and 140 ms (5.6%) in the form-similar priming condition. For both the control subjects and EL, the size of the facilitation did not differ significantly in the identity and form-similar priming conditions, $F(1, 464) = .62, p > .4$, and $F(1, 464) = 2.3, p > .1$, for the control subjects and EL, respectively.

Chi-square tests carried out on error data for EL and the control subjects revealed no significant effect of priming (all χ^2 values < 2).

Discussion

In the present experiment, EL and the two control subjects show evidence of facilitation with both identity and form-similar pseudoword primes, which suggests that the patient can access sublexical phonology in the naming task. Therefore, the present finding argues against Arguin et al.'s (1998) conclusion that pure alexic patients have poor access to sublexical phonology while access to sublexical orthography is spared. Even if pseudowords activate sublexical orthographic representations, these orthographic representations necessarily have to contact some form of phonological representations to make it possible for the patient to pronounce the pseudowords. How could this contact be possible other than through some sort of sublexical orthography-to-phonology conversion? If this conversion is the bottleneck in reading, how can it be that the patients show priming effects in a fast masked priming procedure?

In Experiment 3, EL did not show stronger facilitation with identity primes than with form-similar primes, as if she could not benefit from the additional letter that identity primes have in common with the targets. However, we cannot conclude from this result that EL's sublexical processing is abnormally slow since the control subjects showed the same pattern of performance. The failure to observe stronger facilitation for identity than form-similar primes with both EL and the control subjects can be interpreted in two ways. First, this failure could illustrate the fact that the processing of pseudowords is serial—from left to right—in EL, as in normal readers (see, for example, Rastle & Coltheart, 1998) and too slow to process the entire prime before it is masked. The second possibility is that the lighting characteristics of the testing room were not optimal for obtaining a difference in the size of facilitation. In a footnote, Lukatela, Frost, and Turvey (1998) mention that dim lighting in the test room is crucial for obtaining differences between full and partial phonological (nonword) primes. We did not use this particular lighting condition in our experiment, therefore it is possible that the light was too bright for obtaining differences between identity primes (full phonological primes) and form-similar primes (partial phonological primes). Finally, this failure to obtain differences between three-letter overlap (form-similar) and four-letter overlap (identity) primes makes it unlikely that priming takes place at the level of letter detectors. If it were so, form-similar primes would produce less priming than identity primes.

EXPERIMENT 4

In this final experiment, the processing of sublexical phonology in EL was investigated in greater detail by manipulating the overlap between primes and targets at finer-grain sizes. In the previous experiment, EL appeared to be able to compute some form of sublexical phonology but the design of the experiment did not allow us to determine whether the observed facilitation was due to the processing of the very first letters of the prime or to the processing of the entire prime. The observed identity and form priming effects could be entirely due to the shared onset between primes and targets. In Experiment 4, target words were preceded by the same words (identity priming; e.g., bird/BIRD), pseudohomophones (pseudohomophone priming; e.g., burd/BIRD), pseudowords having the onset in common with the target (onset priming; e.g., bund/BIRD), pseudowords having the phonological rime in common with the target (rime priming; e.g., surd/BIRD), or unrelated words and nonwords (e.g., note/BIRD and jklp/BIRD). In normal adult readers, it has been shown that pseudohomophone primes facilitate word naming over and above onset primes (e.g., Lukatela & Turvey, 1994a, b). In contrast, rime primes tend to inhibit word naming (e.g., Lukatela & Turvey, 1996; Pexman, Cristi, & Lupker, 1999; see discussion). If EL is able to activate sublexical phonological units larger than the onset alone, pseudohomophone primes should be more efficient than onset primes because pseudohomophones are phonologically identical to target words. She might also show inhibition from rime primes. Two control subjects, AS and JD, participated in the experiment.

Apparatus

The apparatus and display conditions of Experiment 4 were identical to those of Experiment 3.

Materials

The stimulus set consisted of 30 four- to six-letter monosyllabic words selected from CELEX (Baayen et al., 1993). Their frequency of occurrence ranged between 41 to 863 per million (mean frequency 227) and their number of orthographic neighbours was 10.6, on average. Each target word was tested under six priming conditions: identity, pseudohomophone, rime, onset, unrelated word, and unrelated nonword (see Table 4). Pseudohomophones were constructed using a database that provides all possible spellings for any given rime pronunciation (Ziegler, Stone, & Jacobs, 1997). For example, the phonological rime of the word BIRD can be spelled either -IRD like in BIRD, -URD like in CURD, -ERD like in HERD, -EARD like in HEARD or -ORD like in WORD. To construct a pseudohomophone of the target word BIRD, we selected the spelling -URD (BURD). Pseudohomophones and target words differed by a single letter. In the rime priming condition, pseudowords were constructed to have the phonological rime in common with the target but a different onset (SURD). In the onset priming condition, pseudowords had the onset in common with the target but a different rime (BUND). Onset and rime primes differed from pseudohomophone primes by a single letter. Onset primes were orthographically as close as possible to pseudohomophone primes in order to ensure that a difference in priming between the two conditions is not due to major orthographic differences between onset and pseudohomophone primes. Similarly, the rime of the rime primes was orthographically identical to the rime of pseudohomophone primes in order to ensure that a difference of priming between the two conditions could not be due to a particular rime. In the unrelated nonword condition, nonwords were consonant strings with no orthographic overlap with target words but the same number of letters (e.g., JKLP). For the unrelated word condition, 30 words were selected from CELEX with no orthographic nor phonological overlap with the target and the same number of letters than other primes (e.g., NOTE). Their frequency of occurrence ranged between 11 to 732 per million (mean frequency 128; Baayen et al., 1993). These two types of unrelated primes (nonwords and words) were used in an attempt to match the related priming conditions better: Some of the related primes were real words (identity) while the others were nonwords (pseudohomophone, rime, onset primes), and some related primes possessed the phonological form of existing words (identity and pseudohomophone primes) while the others did not (rime and onset primes). Unrelated-word, onset, rime, and pseudohomophone primes were balanced on neighbourhood size and neighbourhood frequency (see Table 4). This was done to ensure that primes would not differ in the amount of activation they generated in the lexicon. Therefore, any difference in the results between priming conditions is necessarily due to sublexical factors. All stimuli are listed in Appendix E.

Procedure and design

The procedure of Experiment 4 was identical to that of Experiment 2. Because of the six priming conditions, a given target word was presented six times during a session of the experiment. The 180 trials of the experiment were presented in one single block with two breaks, one every 60 trials. The trials were pseudorandomised so as to avoid the successive presentation of identical targets or targets with the same onset. To increase the number of observations, the patient performed the experiment four times in four different sessions, with an interval of one week or more between two sessions. The trials were pseudorandomised before each session. The two control subjects performed the experiment once.

Results

For the control subjects, latencies above 2 *SD*s from the mean cells were removed from the analyses (3.61 % of the data). Voice key problems caused the removal of 3.06 % of EL's data and another 2.78 % of the control data. Table 5 gives the mean naming latencies and percentage of errors for EL and the control subjects as a function of the priming condition. Figure 5 gives the percentage of net priming in the different priming conditions for EL and the control subjects.

For both EL and the control subjects, the percentage of errors was too small to be submitted to a statistical analysis. There was no speed-accuracy trade-off on EL's data; the correlation between RTs and error rate was positive and nonsignificant (+.01; $p = .82$). As in the previous experiments, we reduced the variance of EL's naming latencies by using a reciprocal transformation (Y' = 1/Y, Kirk, 1982). Correct naming latencies for EL and for the control subjects were submitted to separate item ANOVAs with participant (for control subjects only), session (for EL only), and priming condition as main factors. The ANOVA revealed a significant effect of participants, $F(1, 348) = 944$, $p < .001$, but this effect did not interact with priming condition, $F(5, 348) = 1.44$, $p > .1$. There was no effect of session for EL, $F(3, 696) = 1.9$, $p > .1$. The priming effect was significant for both EL, $F(5, 696) = 8.35$, $p < .001$, and the control subjects, $F(5, 348) = 6.51$, $p < .001$. Contrast analyses showed that, for EL, identity priming produced significant facilitation when compared to both the unrelated nonword and word priming conditions, $F(1, 696) = 21.78$, $p < .001$ and $F(1, 696) = 11.74$, $p < .001$, respectively. The same was true for the control subjects, $F(1, 348) = 6.26$, $p < .05$ and $F(1, 348) = 7.5$, $p < .01$, respectively. For EL, pseudohomophone priming was significantly facilitatory compared to the unrelated nonword priming condition, $F(1, 696) = 3.97$, $p < .05$, but not compared to the word priming condition, $F < 1$. In contrast, for control subjects, pseudohomophone priming was facilitatory compared to both unrelated priming conditions, $F(1, 348) = 12.12$, $p < .001$ and $F(1, 348) = 13.81$, $p < .001$, for the unrelated nonword and unrelated

Table 4. *Characteristics of the primes used in Experiment 4 (standard errors in parentheses)*

Variables (per million)	*Identity (bird)*	*Pseudo-H (burd)*	*Onset control (bund)*	*Rime control (surd)*	*Unrelated word (note)*	*Unrelated nonword (jklp)*
Frequency	227 (234)	–	–	–	128 (146)	–
Ortho. neighbourhood						
Size (N)	–	9.23 (5.73)	8.23 (5.7)	8.87 (6.24)	10.9 (6.08)	0
Frequency	–	484 (489)	394 (363)	388 (418)	491 (660)	0

Table 5. *Mean naming latencies and percentage of errors for the control subjects and EL as a function of the priming condition (standard errors for RTs are given in parentheses)*

	Priming condition	*Control subjects*	*EL*
Mean naming latencies	Identity	598 (16)	1076 (29)
	Pseudohomophone	585 (17)	1182 (30)
	Onset	621 (18)	1192 (33)
	Rime	649 (20)	1407 (56)
	Unrelated nonword	631 (17)	1382 (55)
	Unrelated word	634 (18)	1286 (48)
% errors	Identity	0.00	4.17
	Pseudohomophone	0.00	1.67
	Onset	0.00	2.50
	Rime	0.00	0.83
	Unrelated nonword	0.00	0.83
	Unrelated word	3.33	0.83

word priming conditions, respectively. Pseudohomophone priming was significantly different from identity priming for EL, $F(1, 696) = 7.15, p < .01$, but not for the control subjects,[2] $F < 1$. Pseudohomophone and onset priming were not significantly different for EL, $F < 1$, but they were significantly different for the control subjects, $F(1, 348) = 7.37, p < .01$. The values of net priming in the different priming conditions for EL and the control subjects are given in Table 6.

For EL, onset priming was marginally significant when compared to unrelated nonword priming, $F(1, 696) = 3.5, p = .06$, and not significant when compared to unrelated word priming, $F<1$. For control subjects, the onset priming effects were not significant, both $p > .3$.

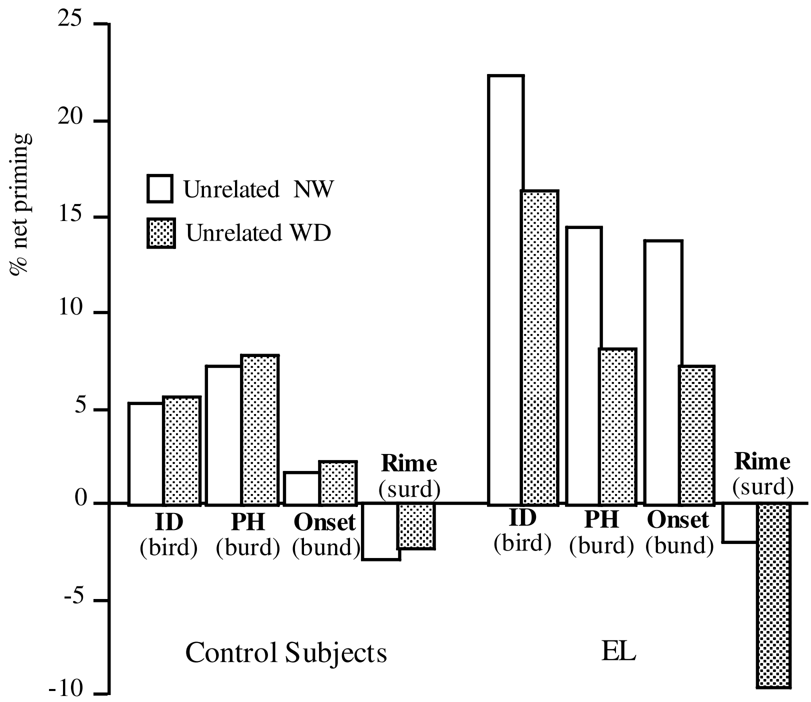

Figure 5. *Percentage of net priming in the identity (ID), pseudohomophone (PH), rime and onset priming conditions for the control subjects and EL.*

[2] The same result was observed in normal readers by Lukatela and Turvey (1994b). According to the authors, pseudohomophone primes can facilitate naming to the same extent as identical primes because phonological information conveyed by pseudohomophones is optimal for naming and the additional information provided by identical primes, i.e., identity, whole-word orthography, and meaning, is not crucial in this task.

Table 6. *Net priming effect (in ms) for the control subjects and EL in the identity, pseudohomophone, rime and onset priming conditions compared to the unrelated (UR) nonword and word priming conditions*

	Control subjects		*EL*	
Priming condition	*UR nonword*	*UR word*	*UR nonword*	*UR word*
Identity	33.1	36.2	307	211
Pseudohomophone	46.1	49.2	200	104 (n.s.)
Onset	10.2 (n.s.)	13.3 (n.s.)	190	94 (n.s.)
Rime	−17.5 (n.s.)	−14.4 (n.s.)	−25 (n.s.)	−121

Rime priming was inhibitory for EL when compared to unrelated word priming, $F(1, 696) = 6.77$, $p < .01$, but not when compared to unrelated nonword priming, $F(1, 696) = 1.8$, $p > .1$. For the control subjects, naming latencies tended to be longer for words preceded by rime primes than for words preceded by unrelated primes (see Figure 5), but this inhibitory effect was not significant (both $p > .1$).

Discussion

Experiment 4 was designed to investigate EL's ability to compute sublexical phonology. Our design included pseudohomophone primes, onset primes, and rime primes. The prediction was that if EL was able to extract phonological information from the entire prime, then she should be faster and more accurate when naming words preceded by pseudohomophones than when naming words preceded by onset primes. At the same time, given that rime priming seems to be inhibitory (Lukatela & Turvey, 1996; but see Montant & Ziegler, 2001), she should be slower and less accurate at naming words preceded by rime primes than words preceded by unrelated primes. This prediction was only partially confirmed as EL did not exhibit higher facilitation for pseudohomophone primes than for onset primes. However, she showed a rime inhibition effect. According to Lukatela and Turvey (1996), the interpretation of this effect is that the presentation of the prime activates a phonological representation, and the successive presentation of the target reinforces, via the rime, the activation of this representation that is not yet stabilised. Therefore, the process of resolving the target's phonological representation takes place against the background of a strongly competing representation of the prime's phonology, which slows down the establishment of the target's phonological code. This process of competing phonological codes might take place as well in EL.

For the control subjects, there was a trend toward rime inhibition but the effect was not significant. This is not very surprising as the actual effect of rime priming—facilitatory vs. inhibitory—in normal readers is still a matter of debate in the literature, and many studies have failed to obtain any effect of rime priming (for a review, see Montant & Ziegler, 2001). If the interpretation of Lukatela and Turvey (1996) is correct, rime inhibition results from dynamical interaction between the prime and the target. In that context, a single aspect of the procedure (the SOA, the lighting of the room) can preclude the emergence of this inhibitory effect.

The fact that EL did not show pseudohomophone facilitation over and above onset facilitation but a rime inhibition as well as a strong identity priming effect (which is significantly greater than both the pseudohomophone and the onset priming effects) suggests that EL can process and extract information from most of the prime but not the entire prime. If we look at the letters of primes and targets from left to right, 73.3% of pseudohomophone and onset primes differ from the target words (and, therefore, from identity primes) by the letter at the third or fourth position from the beginning of the letter strings. Similarly, in rime primes, the nucleus (vowel), which is crucial for determining the pronunciation of the rime, corresponds to the third and/or the fourth letter(s) of the prime in 63.3% of the stimuli used in this experiment. Therefore, in order to get greater facilitation for identity primes than for pseudohomophone and onset primes, and to get a rime inhibition effect, EL must have been processing more than the first three letters of the prime. Given that primes contained either four or five letters, we can conclude that EL was able to process most of each prime in Experiment 4.

The presence of an onset priming effect for the patient suggests that EL was relying more heavily on sublexical processing than the control subjects. In their paper, Forster and Davis (1991) showed that there is no onset effect in naming when the targets are high-frequency words or exception words. They concluded that the onset effect is sublexical. In the present experiment, the targets were high-frequency words (see the characteristics of identity primes in Table 4), and as in Forster and Davis' paper, we found no onset effect with the control subjects. However, EL did show an onset priming effect. This suggests that even high-frequency words in EL are submitted to a sublexical (serial) mode of processing, as they would be if they were not that familiar.

Except for the presence of an onset effect that equals the pseudohomophone effect in size, EL's pattern of performance in this experiment was therefore not fundamentally different from that of control subjects. This suggests that, apart from being slower, the sublexical stages of word processing in EL are qualitatively similar to those of normal readers. As we will see in the General Discussion, a pattern of serial word decoding can be found in normal readers as well in some conditions.

GENERAL DISCUSSION

An interesting but controversial hypothesis has recently been proposed by Arguin, Bub, and Bowers to account for the acquired reading disorder known as pure alexia. In contrast with the increasing popularity of explanations which attribute the disorder to a peripheral deficit, Arguin and colleagues have argued that pure alexia may arise from a postlexical impairment affecting the procedure for converting orthographic to phonological knowledge (Arguin et al., 1998; Bowers et al., 1996b). The goal of this study was to explore this phonological deficit hypothesis with another pure alexic patient. For this purpose, and to be able to make identical comparisons to the data obtained by Arguin and colleagues, we replicated three of their critical experiments to investigate the patient's ability to activate orthographic and phonological information. With a manipulation of word frequency and orthographic neighbourhood size in a naming task, the first experiment was aimed at evaluating the extent of orthographic processing. In this experiment, both IH and EL exhibited a word frequency and a neighbourhood size effect with low-frequency words. According to Arguin et al., these effects can be taken as evidence of relatively spared orthographic processing. We should note that IH's orthographic processing may not be optimal, as revealed in that experiment, as, in contrast with normal subjects and with EL, he also showed facilitation of neighbourhood size on the naming of high-frequency words.

Using homophone primes in a naming task, Experiment 2 was designed to show impaired access to whole-word phonology. Contrary to IH, EL showed evidence of form priming in addition to identity priming. This suggests that EL was able to benefit from phonological (and orthographic) overlap between pseudoword primes and targets. With a wider range of phonological overlap between primes and targets, Experiment 4 was aimed at investigating more extensively EL's ability to access sublexical phonology in naming. Like the control subjects, EL showed evidence of facilitation for both identity and pseudohomophone primes, and inhibition for rime primes. However, contrary to the control subjects, facilitation from pseudohomophone primes was not greater than facilitation from onset primes. This suggests that sublexical processing was too slow in EL to compute more than the onset and the nucleus of the primes. Overall, the results of the present study do not support the hypothesis of a phonological deficit in pure alexia, neither lexical nor sublexical.

So far, the results have been discussed without direct reference to a particular theoretical framework or model. In the remainder of this paper, the phonological deficit hypothesis is examined in the light of recent computational models of word recognition, the Dual Route Cascaded (DRC) model of Coltheart and colleagues (Coltheart, Curtis, Atkins, & Haller, 1993) and the model of Plaut and colleagues (Plaut, McClelland, Seidenberg, & Patterson, 1996; hereafter, the PMSP model). We will discuss whether or not, and if so, how a phonological deficit in these models might possibly account for pure alexia.

The DRC model postulates two routes from spelling to sound: a lexical and a sublexical route. The lexical route is thought to operate by retrieving word pronunciation directly from an internal lexicon. It is therefore based on word-specific associations. In this route, the phonological form of a word is "addressed" as a whole from its orthographic form. The sublexical route, in contrast, uses a letter-to-sound mapping. This mapping is based on explicit rules specifying the most frequent relationship between letters and sounds. The lexical route can "read" all known words, including those with exceptional spelling-to-sound relationships, but no nonwords. The sublexical route can "read" all pronounceable nonwords and all words, except those with exceptional spelling-to-sound correspondences. For any stimulus, both routes work together to activate the phonemes in a phonological output buffer. The lexical route processes all the letters of a word in parallel while the sublexical route operates serially. For high-frequency words, the lexical route will be faster than the sublexical route and therefore will determine the processing of these words. For low-frequency words and for nonwords, the lexical route is slower and the sublexical route can affect the processing of these stimuli.

According to Arguin, Bub, and Bowers, the deficit responsible for pure alexia should arise postlexically, in the form of a partial orthographic/ phonological disconnection. In the frame of the DRC model, a partial disconnection between the orthographic input lexicon and the phonological output lexicon should render problematic the pronunciation of exception words because the phonological form of these words cannot be derived by rule. The disconnection should have limited consequences for the pronunciation of regular words and nonwords. IH shows this pattern of performance, which is known as surface dyslexia, but most pure alexic patients do not. Another prediction from the model is that, with such a disconnection, the word length effect that supposedly arises from a longer clean-up process for longer words should only concern exception words. No exaggerated word length effect should be observed for regular words and nonwords. Such a pattern, however, is not characteristic of pure alexia and was not reported in the articles investigating IH's reading abilities. Another consequence of a disconnection between the orthographic and phonological lexica is that the patient's performance should not be affected in a task that does not require phonological computation (e.g., lexical decision). However, it has repeatedly been shown that the word length effect in pure alexia is not limited to naming but also occurs in lexical decision tasks (e.g., Behrmann et al., 1998a, b; Coslett & Saffran, 1989; Howard, 1991; Patterson & Kay, 1982; Reuter-Lorenz & Brunn, 1990) and in the word identification task (Montant, Nazir, & Poncet, 1998). The postlexical interpretation of pure alexia becomes even more problematic if one were to account for the fact that IH is impaired at processing not only postlexical phonology but also sublexical phonology. In the DRC model, sublexical phonology is computed via the sublexical route. Thus, to account for IH's pattern of naming performance, one would have to assume the presence of two deficits, one postlexically, as originally proposed, and the second sublexically. A way to avoid this noneconomic assumption would be to try to account for IH's pattern using a model, like the PMSP model, in which all letter strings (nonwords, regular and irregular words) are processed according to the same homogeneous mechanisms.

The PMSP model is an interactive neural network in which orthographic, phonological, and semantic information is represented in terms of distributed patterns of activity over separated groups of simple neuron-like processing units. Within each domain, words with partially overlapping structure are represented by similar patterns of activity. In this model, oral reading requires the orthographic pattern for a word to generate the appropriate phonological pattern. This mapping is accomplished via cooperative and competitive interactions among units, including hidden units that mediate between the orthographic, phonological, and semantic units. The network learns this mapping using a back-propagation algorithm. The weights on the connections between units are determined by word frequency and also by subword structure (since words with partially overlapping structure produce similar patterns of activation). In this model, and in other Parallel Distributed Processing (PDP) models (e.g., Seidenberg & McClelland, 1989), the notion of lexicon, and henceforth postlexical and sublexical processes, is irrelevant because "there is nothing in the structure of the system that corresponds to individual words per se, such as lexical entry, localist word units or logogen" (Plaut, 1999, p. 544). Words are distinguished from nonwords only by the functional properties of the system—the way in which particular orthographic, phonological, and semantic patterns of activity interact. Nonwords can activate word patterns as long as they possess a familiar (word-like) subword structure. The fact that nonwords, regular words, and exception words are processed using similar functional mechanisms is one important distinctive feature of the PMSP model, relative to the DRC model.

In the PMSP model, a partial disconnection between orthography and phonology can be due, for example, to an impairment of the hidden units that connect the orthographic and phonological layers. With such an impairment, nonword pronunciations should be harder to generate than word pronunciations because weak phonological activation can be boosted only for learned patterns (i.e., real words) by feedback among co-occurring phonological units and by additional semantic activation[3]. The dissociation that IH shows as a surface dyslexic patient is exactly opposite to this prediction. Moreover, the phonological deficit that he shows as a letter-by-letter reader (Arguin et al., 1998; Bowers et al., 1996a, b) appears to impact all items, independent of whether they are words or nonwords. In an attempt to account for the word length effect on naming latencies, Plaut (1999) implemented a reccurrent network that generates sequential phonological output in response to written input. The exaggerated word length effect that characterises pure alexia was obtained from this model by introducing noise in the letter identification units (Plaut, 1999). Such a deficit is clearly different from the one proposed by Arguin and colleagues, and is more consistent with a peripheral interpretation of the disorder.

In summary, the hypothesis of a phonological deficit responsible for pure alexia is not consistent with current models of visual word recognition, neither dual route nor PDP models. In either case, such a deficit should generate a dissociation between words and nonwords. This dissociation is not observed in pure alexia.

Since IH is a surface dyslexic patient, it might be that the phonological deficit he shows is not related to pure alexia but to surface dyslexia. Several other patients with letter-by-letter surface dyslexia have been described in the literature (e.g., Friedman & Hadley, 1992; Patterson & Kay, 1982). In most of these studies, the authors were concerned with the number of orthographic lexica (one or two) and the locus of the deficit(s) that one has to assume in order to account for the co-occurrence of the two syndromes (pure alexia and surface dyslexia). These studies converge on the conclusion that the association of these dyslexias is due to a deficit affecting the orthographic lexicon or lexica (one for reading and one for spelling, see Patterson & Kay, 1982). None of them makes any claims about a potential phonological problem per se. Surface dyslexia without pure alexia is typically interpreted as resulting from problems in activation in the orthographic lexicon (Behrmann & Bub, 1992). In other cases, it is attributed to a disconnection between orthography and semantics (Patterson et al., 1997). Therefore, the phonological deficit shown by IH is not characteristic of surface dyslexia. It is atypical in both pure alexia and in surface dyslexia.

Taken together, it seems that apart from the word length effect, IH's pattern of reading is fairly different from that of other pure alexic patients. We thus wonder whether the presence of a word length effect among other symptoms should be the only criterion by which to classify a patient as pure alexic or letter-by-letter reader, and whether any patient with a word length effect should be used to inform us about pure alexia. Pure alexia is said to be pure

[3] In the absence of simulation data, we cannot say that such a disconnection will produce the symptoms of phonological dyslexia, although such a disconnection is a very good candidate for phonological dyslexia in the PMSP model.

because it occurs *in the absence* of any other language difficulties (whereas surface dyslexia is often associated with dysgraphia), and it affects all types of letter strings (regular words, exception words, nonwords . . .) without distinction. Therefore, the word length effect alone is probably not sufficient to decide whether someone is a pure alexic patient or not. The absence of other symptoms and the non-specificity of the word length effect seem to be as crucial as the mere presence of the word length effect. Adopting such criteria will not prevent us from giving the same label to patients with different deficits, but at least it will reduce the variability among the population of patients.

Interestingly, the word length effect is not observed in pure alexia only. Under normal conditions of presentation, a word length effect can be observed for normal adult readers as well, but the effect depends of word frequency (Content & Peereman, 1992; Weekes, 1997) and lexical status (Weekes, 1997). A word length effect appears for low-frequency words and for pronounceable nonwords but not for high-frequency words, which suggests that unfamiliar letter strings are more prone to serial processing than familiar words. A word length effect is also observed in beginning readers (Aghababian & Nazir, 2000), which is not surprising if we consider that most printed words are unfamiliar to children and are likely to be processed stepwise, in a grapheme-to-phoneme fashion (Share, 1995). This has two major implications. First, the word length effect is not specific to pure alexia and therefore it should not be taken as the only criterion for deciding whether a patient presents with the syndrome of pure alexia. Second, if normal adult readers and children show a word length effect with unfamiliar words, this means that the word length effect shown by pure alexic patients is not necessarily an artificial "compensatory" strategy (e.g., reverse spelling, Hanley & Kay, 1992) that the patients adopt by default because their reading system is not working anymore.

In a recent paper, Behrmann and colleagues have argued that the residual reading abilities of pure alexic patients emerge from the same system that supported reading premorbidly (Behrmann et al., 1998b). Therefore, the word length effect shown by pure alexic patients may be the exaggerated manifestation of a (serial) mode of word processing that exists in normal reading, and manifests in particular with unfamiliar stimuli. This interpretation implies that when printed words are made orthographically unfamiliar experimentally, normal readers should show (1) a main word length effect in a variety of tasks, independent of the word's characteristics, and (2) a main onset effect in naming. This remains to be tested.

The data that we have collected with EL are consistent with this interpretation. In all the experiments we have conducted, EL shows a pattern of performance quite similar to that of the control subjects, except that she cannot entirely process words or pseudowords presented for very short durations and, therefore, does not show the effects that one would expect from the processing of whole primes in the priming paradigm (Experiments 3 and 4). In contrast, she shows strong onset priming effects that point to a serial mode of word processing. Therefore, it seems that EL is using the normal reading system, and the word length effect she shows comes from a normal procedure that all readers use with unfamiliar letter strings.

To account for the fact that the word length effect is much more dramatic in pure alexic patients than in normal readers, one has to assume that some deficit makes the letter strings appear in a degraded form. The consequence is that all letter strings, words or pseudowords, are processed slowly, following a serial procedure that also exists in normal readers. In the context of current models of word recognition, such a deficit has to be early enough to generate global slowing of the system, independent of the stimuli characteristics in terms of regularity or lexical status. For example, in the DRC model, the deficit has to take place before the separation of the two routes, that is, at the very first stages of word processing. The deficit may be either visual, at the level of feature identification or at the level of letter identification, which is consistent with the accumulating evidence favouring a peripheral deficit in pure alexia (see Behrmann et al., 1998b, for a recent review). The word length effect in the DRC model would arise from the serial mode of processing of the sublexical routine. In the PMSP model, the deficit responsible for pure alexia also has to be early enough in order to slow down the reading system without affecting specifically one layer or the other. The PMSP model can generate an exaggerated word length effect when noise is introduced in the letter units (Plaut, 1999). The introduction of noise affects letter identification. The model is slowed down and has to use step-by-step subword processing to overcome the deficit.

Similarly, the strong lexical and priming effects shown by EL actually support the peripheral account of pure alexia. In all experiments involving familiar items, that is words or word-like pseudowords, EL showed strong lexical effects (frequency, neighbourhood size) and priming effects (identity, homophone, pseudohomophone, onset, and rime priming effects). It is as if "lexical" information, once accessed, was extensively activated to compensate for degraded input. In Experiment 1, EL (and IH as well) exhibited neighbourhood size effects that were about double those of the control subjects. Similarly, EL exhibited a frequency effect 10 times bigger than that of the control subjects. In Experiment 2, EL's facilitation for identity priming and for homophone priming was two to three times bigger than the facilitation obtained with the control subjects. In Experiment 3, where only unfamiliar pseudowords were presented, EL showed the same amount of facilitation as the control subject. Finally, in Experiment 4, EL showed up to nine times more facilitation than the control subjects, depending on the type of prime. Note that, in this experiment, all pseudoword primes, except unrelated nonwords, had a familiar subword structure: The number of orthographic neighbours of these stimuli was nine on average (see Table 4). These strong lexical and priming effects in Experiment 1, 2, and 4 suggest that the subword structure of word-like stimuli is used to enhance perception, via lexical activation (Coltheart et al., 1993) or inter-layer cooperation (Plaut et al., 1996).

Another source of evidence in favour of a peripheral deficit in EL comes from the difference of priming effects obtained in Experiment 4 when using unrelated words or unrelated nonwords primes as a baseline against which priming is accessed. The facilitatory effect of pseudohomophone and onset primes was significant in the comparison with unrelated nonword primes but not in the comparison with unrelated word primes, whereas the inhibitory effect of rime primes was significant in the comparison with unrelated word primes but not in the comparison with unrelated nonword primes. This suggests that, for the patient, unrelated nonword primes tended to be inhibitory whereas unrelated word primes tended to be facilitatory. Consequently, pseudohomophone and onset primes are more facilitatory when compared to the condition that induces inhibition (unrelated nonword) than to the condition that induces facilitation (unrelated words). Similarly, rime primes are more inhibitory when compared to the condition that gives facilitation than to the condition that gives inhibition. The presentation of word primes, even unrelated, seems to generate general lexical activation that benefits the subsequent processing of the target, whereas the presentation of nonword primes seems to inhibit lexical access and perhaps even slows down the processing of the target. Such a subtle difference in the effect of unrelated nonword and word primes might have little impact on an intact reading system but it might have significant impact on a damaged reading system, in particular if the damaged system relies on lexical activation to compensate for a peripheral deficit.

In conclusion, it seems worth pointing out that, in spite of the development of explicit computational models of visual word recognition, a large number of neuropsychological reports do not make reference to these existing models. Often, implicit assumptions are made about the operations and processes involved in reading without a clear description of the reading system. This absence of specification makes it difficult to compare different case descriptions and to evaluate the relevance of the proposed interpretations concerning the understanding of impaired and normal reading. It would indeed be beneficial not only to look for converging evidence from different patients on the same tasks and same stimuli but also to use the existing models of word recognition to constrain the interpretations. This will undoubtedly provide a coherent framework within which to understand both normal and impaired reading.

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REFERENCES

Aghababian, V., & Nazir, T.A. (2000). Developing normal reading skills: Aspects of the visual processes underlying word recognition. *Journal of Experimental Child Psychology, 76*, 123–150.

Andrews, S. (1989). Frequency and neighbourhood size effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 802–814.

Andrews, S. (1992). Frequency and neighbourhood effects on lexical access: Lexical similarity or orthographic redundancy? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 234–254.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighbourhood conflicts. *Psychonomic Bulletin and Review, 4,* 439–461.

Arguin, M., & Bub, D. (1993). Single character processing in a case of pure alexia. *Neuropsychologia, 31*, 435–458.

Arguin, M., Bub, D., & Bowers, J. (1998). Extent and limits of covert lexical activation in letter-by-letter reading. *Cognitive Neuropsychology, 15*, 53–92.

Baayen, R.H., Piepenbrock, R., & Van Rijn, H. (1993). *The CELEX lexical database (CD-ROM).* Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Beauvois, M.F., & Dérouesne, J. (1979). Phonological alexia: Three dissociations. *Journal of Neurology, Neurosurgery and Psychiatry, 42,* 1115–1124.

Behrmann, M., & Bub, D.N. (1992). Two routes, a single lexicon: Evidence from surface dyslexia and surface dysgraphia. *Cognitive Neuropsychology, 9,* 209–251.

Behrmann, M., Nelson, J., & Sekuler, E. (1998a). Visual complexity in letter-by-letter reading: "Pure" alexia is not so pure. *Neuropsychologia, 36*, 1115–1132.

Behrmann, M., Plaut, D.C., & Nelson, J. (1998b). A literature review and new data supporting an interactive account of letter-by-letter reading. *Cognitive Neuropsychology, 15,* 7–51.

Behrmann, M., & Shallice, T. (1995). Pure alexia: An orthographic not spatial disorder. *Cognitive Neuropsychology, 12*, 409–454.

Behrmann, M., Shomstein, S., Barton, J.J., & Black, S.E. (2001). Eye movements reveal the sequential processing in letter-by-letter reading. *Neuropsychologia, 39,* 983–1002.

Berndt, R.S., Haendiges, A.N., Mitchum, C.C., & Wayland, S.C. (1996). An investigation of nonlexical reading impairments. *Cognitive Neuropsychology, 13*, 763–801.

Boles, D.B., & Clifford, J.E. (1989). An upper- and lower-case alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments, and Computers, 12,* 587–596.

Bowers, J.S., Arguin, M., & Bub, D.N. (1996a). Fast and specific access to orthographic knowledge in a case of letter-by-letter reading. *Cognitive Neuropsychology, 13*, 525–567.

Bowers, J.S., Bub, D.N., & Arguin, M. (1996b). A characterisation of the word superiority effect in a case of letter-by-letter surface alexia. *Cognitive Neuropsychology, 13,* 415–442.

Bub, D.N., & Arguin, M. (1995). Visual word activation in pure alexia. *Brain and Language, 49*, 77–103.

Cohen, J.D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments and Computers, 25*, 257–271.

Coltheart, M. (1996). Phonological dyslexia: Past and future issues. *Cognitive Neuropsychology, 13*, 749–762.

Coltheart, M., Davelaar, E., Jonasson, J.T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI.* London: Academic Press.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100*, 589–608.

Content, A., & Peereman, R. (1992). *Single and multiple process models of print to speech conversion.* Amsterdam: North-Holland.

Coslett, H.B., & Saffran, E.M. (1989). Evidence for preserved reading in "pure" alexia. *Brain, 112*, 327–359.

Damasio, A., & Damasio, H. (1983). The anatomic basis of pure alexia. *Neurology, 33,* 1573–1583.

Déjèrine, J. (1892). Contribution a l'étude anatomo-pathologique et clinique des différentes variétés de cécité-verbale. *Mémoires Sociéte Biologique, 4,* 61–90.

Ekstrom, R., French, J.W., & Harman, H.H. (1976). *Manual for kit of factor-referenced cognitive tests.* Princeton, NJ: Educational Testing Service.

Everitt, B.S. (1972). *The analysis of contingency tables.* London: Chapman & Hall.

Farah, M.J. (1990). *Visual agnosia: Disorders of object recognition and what they tell us about normal vision.* Cambridge, MA: MIT Press.

Farah, M.J., & Wallace, M. (1991). Pure alexia as a visual impairment: A reconsideration. *Cognitive Neuropsychology, 8*, 313–334.

Forster, K.I., & Davis, C. (1991). The density constraint on form-priming in the naming task: interference effects from a masked prime. *Journal of Memory and Language, 30,* 1–25.

Friedman, R.B., & Hadley, J.A. (1992). Letter-by-letter surface alexia. *Cognitive Neuropsychology, 9,* 1–23.

Gathercole, S.E., Willis, C.S., Baddeley, A.D., & Emslie, H. (1994). The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory, 2*, 103–127.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language, 33,* 218–233.

Greenblatt, S.H. (1976). Subangular alexia without agraphia or hemianopsia. *Brain and Language, 3,* 229–245.

Hanley, J.R., & Kay, J. (1992). Does letter-by-letter reading involve the spelling system? *Neuropsychologia, 30*, 237–256.

Hanley, J.R., & Kay, J. (1996). Reading speed in pure alexia. *Neuropsychologia, 34*, 1165–1174.

Henderson, V.W. (1986). Anatomy of posterior pathways in reading: A reassessment. *Brain and Language, 29*, 119–133.

Howard, D. (1991). Letter-by-letter readers: Evidence for parallel processing. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 34–76). Hove, UK: Lawrence Erlbaum Associates Ltd.

Humphreys, G.W., Evett, L.J., & Taylor, D.E. (1982). Automatic phonological priming in visual word recognition. *Memory and Cognition, 10,* 576–590.

Kirk, R.E. (1982). *Experimental design* (2nd ed.). Monterey, CA: Brooks/Cole Company.

Kučera, M., & Francis, W. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Leff, A.P., Crewes, H., Plant, G.T., Scott, S.K., Kennard, C., & Wise, R.S.J. (2001). The functional anatomy of single-word reading in patients with hemianopic and pure alexia. *Brain, 124*, 510–521.

Lukatela, G., Frost, S.J., & Turvey, M.T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory and Language, 39*, 666–683.

Lukatela, G., & Turvey, M.T. (1994a). Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123,* 107–128.

Lukatela, G., & Turvey, M.T. (1994b). Visual lexical access is initially phonological: 2. Evidence from phonological priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 331–353.

Lukatela, G., & Turvey, M.T. (1996). Inhibition of naming by rhyming primes. *Perception and Psychophysics, 58,* 823–835.

McCann, R.S., & Besner, D. (1987). Reading pseudohomophones: Implications for models of pronunciation and the locus of word-frequency effects in word naming. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 14–24.

McClelland, J.L., & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375–407.

Montant, M., Nazir, T.A., & Poncet, M. (1998). Pure alexia and the viewing position effect in printed words. *Cognitive Neuropsychology, 15*, 93–140.

Montant, M., & Ziegler, J.C. (2001). Can rime primes facilitate naming? *Psychonomic Bulletin and Review, 8,* 351–356.

Mycroft, R., Behrmann, M., & Kay, J. (2001). *Letter-by-letter reading: A visual processing difficulty whose effects are most marked with words.* Submitted for publication.

Patterson, K., Graham, N., & Hodges, J.R. (1994). Reading in dementia of the Alzheimer type: A preserved ability? *Neuropsychology, 8,* 395–407.

Patterson, K.E., & Hodges, J. (1992). Deterioration of word meaning: Implications for reading. *Neuropsychologia, 30*, 1025–1040.

Patterson, K.E., & Kay, J. (1982). Letter-by-letter reading: Psychological descriptions of a neurological syndrome. *Quarterly Journal of Experimental Psychology, 34A,* 411–441.

Patterson, K., Plaut, D., McClelland, J.L., Seidenberg, M.S., Behrmann, M., & Hodges, J.R. (1997). *Connections and disconnections: A connectionist account of surface dyslexia.* New York: World Scientific.

Peereman, R., & Content, A. (1995). The neighbourhood size effect in naming: Lexical activation or sublexical correspondences. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 409–421.

Peereman, R., & Content, A. (1997). Orthographic and phonological neighbourhood in naming: Not all neighbours are equally influential in orthographic space. *Journal of Memory and Language, 37,* 382–410.

Pexman, P.M., Cristi, C., & Lupker, S.J. (1999). Facilitation and interference from formally similar word primes in a naming task. *Journal of Memory and Language, 40,* 195–229.

Plaut, D.C. (1999). A connectionist approach to word reading and acquired dyslexia: Extension to sequential processing. *Cognitive Science, 23*, 543–568.

Plaut, D.C., McClelland, J.L., Seidenberg, M., & Patterson, K.E. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56–115.

Pollatsek, A., Perea, M., & Binder, K. (1999). The effect of "neighbourhood size" in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1142–1158.

Rastle, K., & Coltheart, M. (1998). Whammy and double whammy: Length effects in nonword naming. *Psychonomic Bulletin and Review, 5,* 277–282.

Reuter-Lorenz, P., & Brunn, J. (1990). A prelexical basis for letter-by-letter reading: A case study. *Cognitive Neuropsychology, 7,* 1–20.

Saffran, E.M., & Coslett, H.B. (1998). Implicit vs. letter-by-letter reading in pure alexia: A tale of two systems. *Cognitive Neuropsychology, 15*, 141–165.

Seidenberg, M., & McClelland, J. (1989). A distributed developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.

Sekuler, E.B., & Behrmann, M. (1996). Perceptual cues in pure alexia. *Cognitive Neuropsychology, 13*, 941–974.

Shallice, T., & Saffran, E. (1986). Lexical processing in the absence of explicit word identification: Evidence from a letter-by-letter reader. *Cognitive Neuropsychology, 3*, 429–458.

Share, D.L. (1995). Phonological recoding and self-teaching: sine qua non of reading acquisition. *Cognition, 55,* 151–218.

Snodgrass, S.G., & Vanderwart, M.A. (1980). A name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 6,* 174–215.

Tagamets, M.A., Novick, J. M., Chalmers, M.L., & Friedman, R.B. (2000). A parametric approach to orthographic processing in the brain: An fMRI study. *Journal of Cognitive Neuroscience, 12,* 281–297.

Tarkianen, A., Helenius, P., Hansen, P.C., Cornelissen, P.L., & Salmelin, R. (1999). Dynamics of letter string perception in the human occipitotemporal cortex. *Brain, 122*, 2119–2131.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E.D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124,* 107–136.

Warrington, E.K., & Shallice, T. (1980). Word-form dyslexia. *Brain, 103*, 99–112.

Weekes, B.S. (1997). Differential effects of number of letters on word and nonword naming latency. *Quarterly Journal of Experimental Psychology, 50A*, 439–456.

Wilson, B., Cockburn, J., & Halligan, P.W. (1987). *Behavioural Inattention Test.* Suffolk, UK: Thames Valley Test Company.

Ziegler, J.C., Stone, G.O., & Jacobs, A.M. (1997). What's the pronunciation for -OUGH and the spelling for /u/? A database for computing feedforward and feedback inconsistency in English. *Behavior Research Methods, Instruments, and Computers, 29,* 600–618.

APPENDIX A

EL's spontaneous speech in picture description

Picture 1. Children and dad playing on the beach

EL: "It's a beach scene. There's a boy building a sand castle. There's a dad and his little boy playing ball, and there's a guy standing in a boat, tss-tss-tss, and he's falling all over the boat. Oh, there's a pier and some of those changing pavilions and two seagulls or pelicans."

Picture 2. Biker in trouble on the roadside

EL: " This is a biking problem. Looks like the wheel, the front wheel fell off of the bike and the bike rider is hailing help, he's hailing for the car that comes to help him."

APPENDIX B

Stimuli of Experiment 1

High frequency		*Low frequency*		*High frequency*		*Low frequency*	
LN	*HN*	*LN*	*HN*	*LN*	*HN*	*LN*	*HN*
ABLE	BACK	ACRE	COKE	ALSO	BALL	ARCH	BALE
AREA	CARE	BLUR	CONE	BODY	CASE	CHAR	BEAD
AWAY	COLD	EARL	DINE	BOTH	COME	CHEF	BOOT
BLUE	DATE	EDEN	DOLE	DOES	CORE	CYST	BULL
CITY	FIRE	FERN	DUCK	ELSE	DEAL	DUKE	CAKE
CLUB	FULL	FETE	FAKE	FREE	DONE	FUME	CAVE
DATA	GAVE	FRET	FOLD	FROM	FALL	GLEN	DAME
DOWN	HARD	FROG	GORE	HIGH	FEAR	JADE	DANE
EACH	HAVE	FUSE	HACK	INTO	FILE	LIMB	DENT
EVEN	HEAD	FUSS	LACE	KEPT	FINE	LISP	FORE
GIRL	HOLD	GENE	LAME	MUCH	GAME	LOAF	GALE
MANY	HOLE	GREY	LICE	ONCE	HART	NORM	GALL
NEWS	LATE	HAWK	LONE	OPEN	LACK	OILY	HARE
ONLY	LEAD	JOWL	LOOT	OVER	LAST	OXEN	HEAL
PLAY	MORE	KELP	MASH	PLAN	LINE	PONY	HOOT
TOWN	MUST	LIED	MOLE	SIZE	LOST	PREY	HOSE
TRUE	NEAR	OATS	RAKE	SUCH	LOVE	SEWN	LASH
TYPE	RACE	PITY	RAVE	THEY	MAKE	SILO	LENT
UNIT	RATE	PROD	REED	THIS	MALE	THUD	LORE
USED	READ	ROMP	SEAR	THUS	PAST	THUG	LUST
WAYS	ROLE	ROSY	SLOT	UPON	SALE	TOMB	NAIL
WHAT	WALL	VOID	VALE	VARY	SAME	TROT	PATE
WHEN	WAVE	WEPT	VEST	VIEW	SENT	VEER	PEAR
WHOM	WIDE	WIRY	WALE	WALK	TAKE	WATT	SAGE
WONT	YEAR	WITS	WART	WITH	WENT	WISP	TAME

LN = low neighborhood; HN = high neighborhood.

APPENDIX C

Stimuli of Experiment 2

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

APPENDIX D

Stimuli of Experiment 3

Identity		*Form similar*		*Unrelated 1*		*Unrelated 2*	
Prime	*Target*	*Prime*	*Target*	*Prime*	*Target*	*Prime*	*Target*
alar	ALAR	aman	AMAR	aman	TADE	alar	BEEL
alta	ALTA	beed	BEEL	beed	ALTA	alta	RAME
bame	BAME	belb	BELD	belb	ALAR	bame	FREG
bebt	BEBT	dagg	DAGE	dagg	BLID	bebt	TALA
blap	BLAP	dain	DAIL	dain	BLAP	blap	DAGE
blid	BLID	deag	DEAT	deag	LARN	blid	DEAT
bram	BRAM	fagg	FAGE	fagg	BRAM	bram	FAGE
dalf	DALF	fraa	FRAB	fraa	DALF	dalf	AMAR
dall	DALL	freb	FREG	freb	BAME	dall	MEED
deet	DEET	gann	GAND	gann	DEET	deet	HARG
frad	FRAD	glan	GLAG	glan	RILD	frad	LALE
garm	GARM	glar	GLAT	glar	NADE	garm	JEAL
gart	GART	glag	GLAW	glag	PABE	gart	RELL
gire	GIRE	harl	HARG	harl	BEBT	gire	RALL
graw	GRAW	jear	JEAL	jear	DALL	graw	REET
gree	GREE	lall	LALE	lall	GIRE	gree	LARB
jerb	JERB	larl	LARB	larl	REAN	jerb	GAND
lage	LAGE	leab	LEAT	leab	GARM	lage	TERB
lare	LARE	meeq	MEED	meeq	LARE	lare	TEAD
larn	LARN	narr	NARD	narr	RILL	larn	TEEL
lart	LART	rala	RALD	rala	JERB	lart	TEAL
lert	LERT	ralb	RALL	ralb	GREE	lert	GLAG
nade	NADE	ramd	RAME	ramd	LERT	nade	GLAT
pabe	PABE	reeb	REET	reeb	LART	pabe	GLAW
pard	PARD	rele	RELL	rele	PARD	pard	LEAT
parl	PARL	tald	TALA	tald	GRAW	parl	BELD
rean	REAN	teab	TEAD	teab	GART	rean	DAIL
rild	RILD	teag	TEAL	teag	PARL	rild	NARD
rill	RILL	teeq	TEEL	teeq	LAGE	rill	RALD
tade	TADE	tern	TERB	tern	FRAD	tade	FRAB

APPENDIX E

Stimuli of Experiment 4

Priming conditions						
Identity	*Onset*	*PH*	*Rime*	*Unrelated word*	*Unrelated nonword*	*Target*
bird	bund	burd	surd	note	jklp	BIRD
blame	blarm	blaim	glaim	court	gtfcv	BLAME
boat	bose	bote	hote	sell	kprx	BOAT
brain	brafe	brane	prane	cough	cjklp	BRAIN
clear	cleur	cleer	sleer	south	tfbnd	CLEAR
dance	dande	danse	canse	flush	tbvkm	DANCE
door	doir	doar	woar	mean	fpch	DOOR
feel	fean	feal	beal	cost	pkjd	FEEL
firm	feam	ferm	serm	mass	tdgs	FIRM
first	forst	furst	turst	pound	mbfpc	FIRST
force	fouse	forse	lorse	shake	cmlpq	FORCE
game	gaid	gaim	baim	drop	drsc	GAME
girl	garl	gurl	surl	send	jpxw	GIRL
green	greal	grean	brean	block	tvcds	GREEN
hope	horp	hoap	woap	sign	cxtk	HOPE
horse	hoice	horce	torce	train	fgvcb	HORSE
hurt	hort	hert	nert	fold	gfbl	HURT
joke	jonk	joak	voak	plus	hgtd	JOKE
keep	kenp	keap	meap	burn	tfcv	KEEP
pause	paize	pauze	mauze	floor	hmcqb	PAUSE
prove	prave	pruve	druve	black	sdtmf	PROVE
same	saip	saim	haim	help	vdtl	SAME
search	sorch	surch	gurch	float	gbnkv	SEARCH
seat	seef	seet	keet	fond	nhtl	SEAT
share	shait	shair	ghair	frown	bgtfk	SHARE
shoe	shul	shue	thue	blur	vlpr	SHOE
soul	soad	soal	loal	warm	hgcm	SOUL
true	traw	trew	frew	blond	hdfc	TRUE
word	wond	wird	fird	farm	gtcj	WORD
worth	warth	wirth	nirth	bleak	cxnjk	WORTH