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Visual complexity in letter-by-letter reading: "Pure" alexia is not pure

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Abstract—Standard accounts of pure alexia have favoured the view that this acquired disorder of reading arises from damage to a left posterior occipital cortex mechanism dedicated to the processing of alphanumeric symbols. We challenge these accounts in two experiments and demonstrate that patients with this reading deficit are also impaired at object identification. In the first experiment, we show that a single subject, EL, who shows all the hallmark features of pure alexia, is impaired at picture identification across a large set of stimuli. As the visual complexity of pictures increases, so EL's reaction time to identify the stimuli increases disproportionately relative to the control subjects. In the second experiment, we confirm these findings with a larger group of five pure alexic patients using a selected subset of high- and low-visual complexity pictures. These findings suggest that the deficit giving rise to pure alexia is not restricted to orthographic symbols *per se* but, rather, is a consequence of damage to a more general-purpose visual processing mechanism. © 1998 Elsevier Science Ltd. All rights reserved.

Key Words: pure alexia; letter-by-letter; reading, object identification; occipital lobe; visual complexity.

Introduction

The processing of written language is a cognitive ability that is acquired relatively late both phylogenetically and ontogenetically. Whereas spoken forms of language have been around for some 100,000 years, written language is recent and barely 5,000 years old. Similarly, whereas spoken language is acquired in the first two years of life, written language (acquired largely through focused instruction) is acquired in about the sixth year of life for the majority of children [2]. An outstanding question is what brain structures mediate the processing of written language. One possibility is that there are particular brain structures that have evolved and become dedicated to the conversion of orthography to phonology. An alternative view is that the brain structures that support written language are more general-purpose, extending beyond the realm of written language to serve many cognitive functions. These more general-purpose mechanisms are then recruited in the service of this newly-acquired cognitive skill. If brain damage can selectively impair written language, leaving all other cognitive behaviors intact, this would suggest that there might indeed be independent mechanisms or modules that subserve the particular cognitive function of processing written language. On the other hand, if written language simply "piggy-backs" on other existing visual and linguistic skills, then one might expect that when reading (alexia) or writing (agraphia) deficits are acquired in adulthood, additional, more fundamental visual and/or linguistic processes would also be adversely affected. We first review existing findings relevant to the issue of dedicated reading mechanisms and then present our empirical data from neuropsychological patients with acquired reading impairments.

Acquired dyslexia and more general cognitive abilities

A number of recent studies of premorbidly literate adults with acquired reading deficits have attempted to adjudicate between the view that region(s) of the brain are dedicated (perhaps exclusively so) to reading and the view that reading is mediated by more general perceptual and cognitive abilities. This controversy is currently being debated in the context of two forms of acquired dyslexia, phonological dyslexia and acquired surface dyslexia, each of which we discuss in turn.

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Phonological alexia is an impairment in which patients read real words well (both regular and irregular) but are significantly impaired at pronouncing legal non-words (e.g. MAVE or FINT). Previous accounts have argued that the disorder arises from an impairment to the rule-governed grapheme-to-phoneme procedure or assembled spelling route and is thus highly specific to processes of reading [17, 32]. This account has been increasingly challenged, however; for example, Beauvois and Derousne [4] proposed that the deficit extends beyond reading and arises from a problem in blending phonological elements into a co-ordinated pronunciation. Interestingly, all 17 phonological dyslexia patients described in the special issue of the journal, *Cognitive Neuropsychology* on phonological dyslexia, exhibited a more general phonological deficit as evidenced in non-reading phonological tasks that required blending or segmentation [11, 29, 53]. Taken together, the data suggest that the reading deficit likely arises from an impairment of a more general phonological impairment rather than from a specific reading ability.

Evidence for a general underlying deficit has also been obtained for a second form of acquired dyslexia, although the exact nature of this general deficit is somewhat more controversial than in the case of phonological dyslexia. Surface dyslexia is an impairment in which the reading of exception words is impaired while regular word and non-word reading is preserved [57]. The long-standing explanation of surface dyslexia is that it arises from a lesion to the whole-word or direct route to printed word recognition [19, 20, 48]. Recently, however, Patterson *et al.* have argued that surface dyslexia may be attributable to a more general deficit in semantic memory rather than to a specific orthographic process. More specifically, Patterson *et al.* claim that the concatenation of subword phonological elements might suffice for regular words and non-words but that semantic knowledge is needed to retrieve the phonology for irregular items for which spelling-to-sound correspondences are inadequate [55, 61]. Empirical support for the involvement of semantics in irregular word reading comes from the finding that patients with surface dyslexia almost always have an associated semantic deficit and moreover, the availability of semantic knowledge predicts reading success of irregular words on an item-by-item basis [36, 75]. Additionally, although both regular and exception word reading deteriorate with increasing semantic impairment, the decline is sharper for the exception words [54, 72]. These findings are consistent with the claim that surface dyslexia is a consequence of a deficit to a general cognitive ability, in this case, semantic memory. Although support for this view is strong, there are some cases which challenge this particular interpretation and require resolution [15, 46] and the issue requires further debate.

Pure alexia and more general cognitive abilities

The findings from the studies of phonological and surface dyslexia suggest that the reading impairments are attributable to a more general deficit in phonological processing and semantic memory, respectively. Both phonological and surface dyslexia are "central" forms of acquired dyslexia [69] and the underlying deficits are assumed to arise in the more linguistic processes involved in reading. A similar question concerning dedicated vs general-purpose mechanisms may be addressed to the more "peripheral" forms of acquired dyslexia. Indeed, the controversy concerning whether the reading deficit arises from more general-purpose vs more dedicated mechanisms has perhaps been played out most explicitly with reference to the peripheral form of reading deficit known as "pure" alexia.

The term "pure alexia" was coined to reflect the fact that patients with this disorder, acquired after posterior left hemisphere lesions, were thought to be impaired at recognizing and identifying orthographic material while other visual and cognitive abilities were largely spared [24, 33]. If any additional cognitive deficits were observed in these patients such as color deficits, anomia or memory deficits, they were, at most, mild, or, in the case of the memory deficit, a result of a more extensive lesion which implicated additional temporal lobe regions [14, 23]. A more recent instantiation of this same view is that there exists in the posterior left hemisphere a visual word-form system in which orthographic information is selectively represented and it is this mechanism that is either damaged or inaccessible in these patients [37, 74]. Evidence consistent with this orthographic-specific system also comes from neuroimaging studies in which left medial extrastriate activation is found only for real words and legal pseudowords, once activation from false-font stimuli or random consonants is subtracted away [58] (for review see [59]).

The existence of a truly independent orthographic system, however, has been challenged recently. Farah [27, 28], for example, has argued strongly that reading relies on some of the same visual mechanisms used for processing other perceptual material. Even when the reading deficits appear in relative isolation (and it is in these cases that the question of a dedicated word-form system is most relevant), it may still be the case that the same visual systems are utilized but that reading may simply be especially vulnerable. Because letters are highly confusable and not easily predicted from other letters in the input and because almost all, if not all, of the letters in a string must be identified for word recognition, reading is a particularly difficult and taxing task. Thus, even following mild brain damage, reading may be impaired while other visuoperceptual abilities may be relatively (but not totally) spared.

There have, however, only been a few attempts to examine the non-reading perceptual abilities of pure alexic patients in detail. In one important early study, Kinsbourne and Warrington [42] showed that patients with pure alexia are impaired at recognizing multiple shapes presented tachistoscopically, irrespective of whether they were letters or pictures. More recently, Farah and Wallace [30] reported that their patient, TU, performed poorly on tests of perceptual fluency, in which perceptual tasks are performed under time limitations and that the poor performance applied to the processing of alphanumeric and of non-orthographic stimuli. Sekuler and Behrmann [67] replicated the Farah and Wallace result with four pure alexia patients and also showed that these patients were impaired in visual processing under stringent testing conditions: for example, the patients did not show the benefit that usually accrues when processing the attributes of a single object relative to two objects [9, 25]. Based on these findings, Sekuler and Behrmann (1996) suggested that all four of these patients suffered from a general perceptual deficit which extended beyond their ability to process orthographic material.

If it is indeed the case that pure alexia results from a more general perceptual problem and is not as "pure" as originally suggested, then we might also expect these patients to have difficulties in the recognition of objects [27, 28]. While these patients are not floridly agnosic, more fine-grained tests of their object recognition have suggested some subtle problems. Friedman and Alexander [31], for example, demonstrated that their pure alexic patient was not only impaired at the identification of letters but was also poor at recognizing objects presented visually. The patient revealed an elevated threshold, relative to that of normal subjects, for identifying briefly presented pictures taken from the high name-agreement set of Snodgrass and Vanderwart items [71]; whereas normal subjects required 30 ms for identifying pictures, their pure alexic patient required 50 ms for identifying both words and pictures. Interestingly, this patient could identify the pictures from the Boston Naming Test [35] well but, under the more rigorous tachistoscopic testing, showed an impairment relative to the normal controls.

The goal of the present article is to evaluate whether other patients classified as pure alexic readers would be impaired in picture identification as would be predicted if the deficit affected a general-purpose visual processing system. In the first experiment, we demonstrate that a single pure alexic reader is impaired at picture identification across a large set of stimuli and show that as visual complexity increases, so the reaction time to identify the pictures increases disproportionately relative to control subjects. In the second experiment, we confirm this finding with a larger group of pure alexic patients using a selected subset of high- and low-visual complexity pictures. For the remainder of this article, we refer to pure alexic patients as letter-by-letter readers (LBL) to be more consistent with our claim that they have a more widespread perceptual deficit that extends beyond orthography.

Section 1: Picture Identification in a Single LBL Reader

In this first section, we describe and compare the reading and perceptual performance of a single LBL subject, EL, with that of two matched control counterparts. We first present the case report in some detail to verify that EL matches the profile of a LBL reader. We then describe findings from studies of EL's perceptual abilities and finally, report the data from the critical picture identification experiment.

Case report

EL is a 48-year-old right-handed, English-speaking female with a history of mitral valve prolapse who was admitted to the hospital in April 1996. Sadly and ironically, EL was a teacher of reading and taught dyslexic children. After sustaining two recent embolic events causing left arm weakness, blurred vision and slurred speech, EL was diagnosed as having bacterial endocarditis. A CT scan performed at the time of admission revealed a large, chronic infarction with necrosis and cavitation in the territory of the left posterior cerebral artery involving the left occipital and temporal cortices, including peristriate inferotemporal visual association cortex and lateral posterolateral temporal neocortex. Medial striate cortex appears to be spared, even on the proton density sequences but dorsal parietal cortex in the vicinity of the occipitoparietal cortex appears to be involved. The magnetic resonance angiogram of 16 October 1997, demonstrates no flow in the territory of the parieto-occipital branches of the left PCA. No right hemispheric nor posterior fossa abnormalities were seen. At the time of testing, EL had a right quadrantanopsia. All stimuli were consequently presented in her intact left visual field. Figure 1 shows two slices from a MRI scan taken in 1996.

EL performed well within the normal range on the Benton facial recognition test [10], scoring a total of 45 where the normal range is 41–54. EL also revealed no difficulties in writing; her spelling was good as tested on the 40 words from the PALPA subtest (44) where she made only a single error (AEROPLANE -> aireoplane). EL performed well on the standardized Visual Object and Space Perception Battery (VOSP) [73], scoring perfectly on the shape screening test, incomplete letters subtest, dot counting and position discrimination, number location and cube analysis. Her performance on the silhouette subtest (23/30), object decision (18/20) and progressive silhouettes (9/20), while not perfect, are all within one point, either above or below, of normal performance. EL is able to identify single uppercase letters presented briefly on a computer screen at the limits of the computer (17 ms) without masking. These findings suggest that EL does not exhibit any very obvious visual agnosia under these testing conditions.

Two age- and education-matched control subjects, AS and JD, with no history of neurological illness, participated in the following experiments unless reported otherwise. Their data are averaged and constitute a benchmark against which to compare EL's performance.

Naming latency and lexical decision. This section

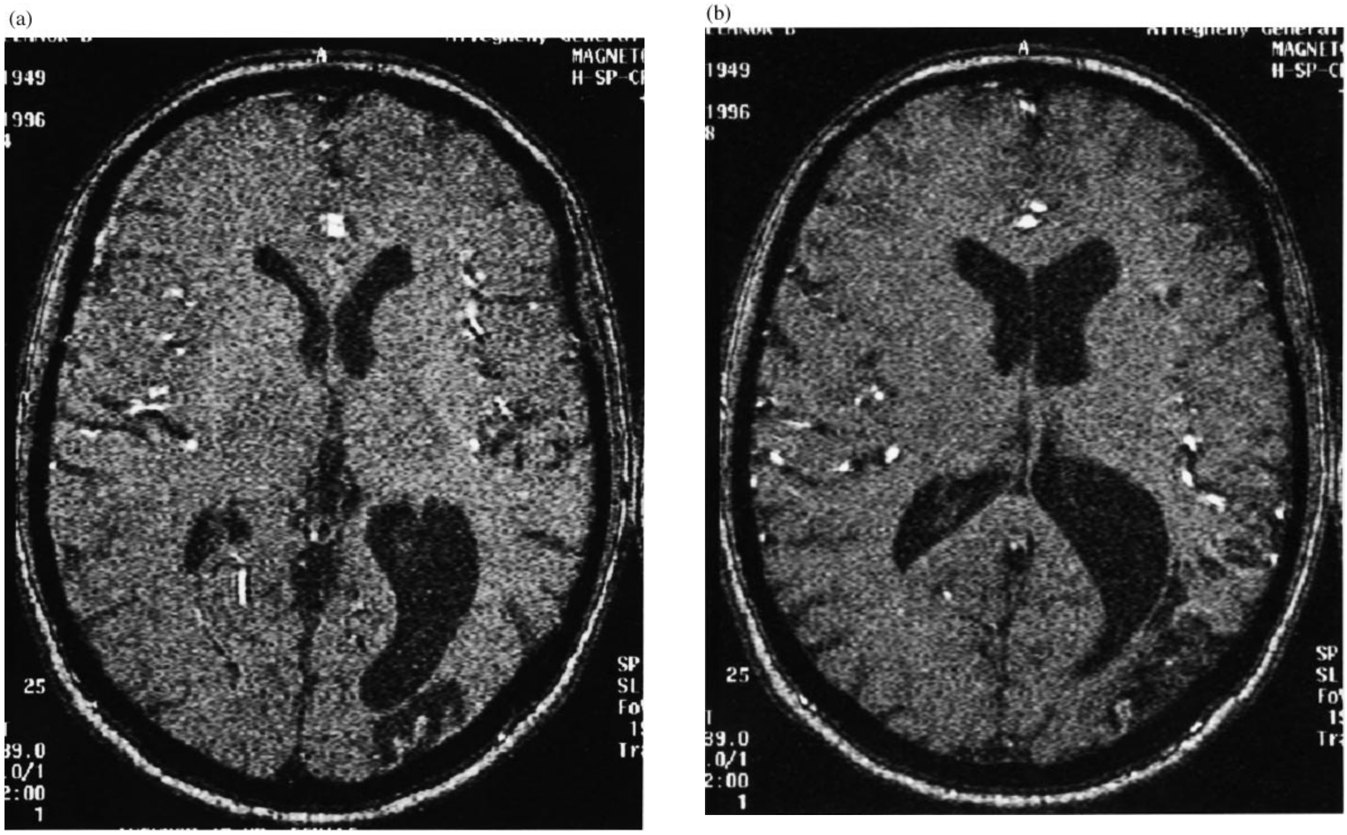

Fig. 1. Two slices from the MRI scan for patient EL showing extensive occipitotemporal lobe involvement on the left (see text for further details).

describes EL's word recognition abilities relative to the control subjects.

Apparatus and material. A single letter string of three-, five- or seven-letters was presented on a computer screen to the left of fixation. For the naming latency task, EL was required to read aloud the word as quickly and as accurately as possible. For the lexical decision task, she was instructed to make "yes" and "no" responses to the letter string with her dominant right hand using the rightmost and leftmost keys on the button box, respectively. The visual angles subtended by three-, five- and seven-letter-words were 0.5° vertically and 1.5°, 2.4° and 3.6°, respectively. The words or non-words were presented individually and remained on the screen until a response was made. Both speed and accuracy were measured as a function of word length. For the purposes of analysis, the data from the two control subjects were combined and compared with those of EL.

All aspects of stimulus control and presentation were controlled by a 540C Macintosh Powerbook computer using PsyScope [16], except as noted. A voice key, interfaced with PsyScope, was used to measure vocal RT and the experimenter kept a record of accuracy. When responses required a manual keypress, a button box was used to record latency and accuracy.

Stimuli For naming latency, 30 items each of three-, five- and seven-letter words, were selected. Frequency and imageability were orthogonally crossed with word length in these lists. The cut-off for frequency was 20 per million with items below that classified as low frequency and items above that classified as high in frequency [44]. Imageability ratings were taken from the MRC Database [18] and items exceeding 525 were classified as high in imageability and those below this cut-off as low in imageability (imageability runs from 0–700 in these scales). In a second session, a month later, 60 of these same items, equally divided into the three word lengths, were presented again just to EL but for a brief exposure duration (33 ms, no mask) and accuracy was recorded as a function of word length.

For the lexical decision task, 60 new words were selected using the criteria outlined above. The non-words were constructed from the word strings as follows: for three-letter words, a single letter was altered whereas for words of five- and seven-letters, two letters were altered. In most cases, the vowels were altered and all non-words were orthographically legal.

Results and discussion. EL made only one error in the unlimited duration naming latency task (TRIBUTE -> "tribe") and the normal control subjects made no errors. To examine the effect of word length on naming latency, we performed a repeated measures ANOVA on the items with word length (three, five, seven) as a within-subject variable and group (patient/control) as a between-subject variable. RT on correct trials served as the dependent measure. Figure 2a shows the mean RTs, as a function of word length for EL and the controls as well as the 5th and 95th percentile boundaries for the normal subjects. As is evident from this figure, there is a significant interaction between group and word length, ($F(2,78) = 19.6$, $P < 0.0001$); whereas control subjects show an increase of 9.4 ms for each additional letter, EL shows an increase of 728.75 ms as determined by a regression analysis with word length set against RT. The slope of the function for the control data is significantly different from zero and the correlation between RT and word length is 0.31 ($r^2 = 0.09$; $t(79) = 2.9$, $P < 0.01$). There are also significant main effects both for group, ($F(1,78) = 136.9$, $P < 0.0001$), with EL's RTs slower overall than the controls and for word length, ($F(2,78) = 20.2$, $P < 0.0001$), with slower RTs for longer items. The increase in RT as a function of word length is mirrored in EL's accuracy of report as a function of word length when the words are presented for a brief duration: her accuracy is 100, 40 and 35% for three-, five- and seven-letter words, respectively.

EL made seven errors on the lexical decision task (one each on three- and five-letter strings and five errors on seven-letter strings) and the controls averaged four errors. The analysis of the RTs from the lexical decision task was carried out using a repeated measures ANOVA with length (three, five, seven) and lexicality (word, non-word) as within-subject factors and group as a between-subjects factor. This analysis revealed a significant difference between EL and the controls as a function of string length, ($F(2,101) = 46.8$, $P < 0.0001$) and this held equally for words and non-words; whereas the control subjects were 88 ms slower on seven-letter than three-letter strings, EL was 3929 ms slower. Figure 2b shows the mean RTs for words and non-words for EL and the controls as well as the 5th and 95th percentile points for the control subjects. The regression slopes were again calculated by setting string length against RT. As is the case for the naming latency data, there is a small but significant influence of string length for the control subjects, with a slope of 32.2 ms for words and 12.5 for non-words. A correlation analysis between word length and RT for the control subjects revealed a correlation of 0.41 ($r^2 = 0.16$; $t(79) = 2.3$, $P < 0.05$). The slope for EL is considerably exaggerated with values of 967.2 ms and 996 ms for words and non-words, respectively. There were also significant main effects both, for group,

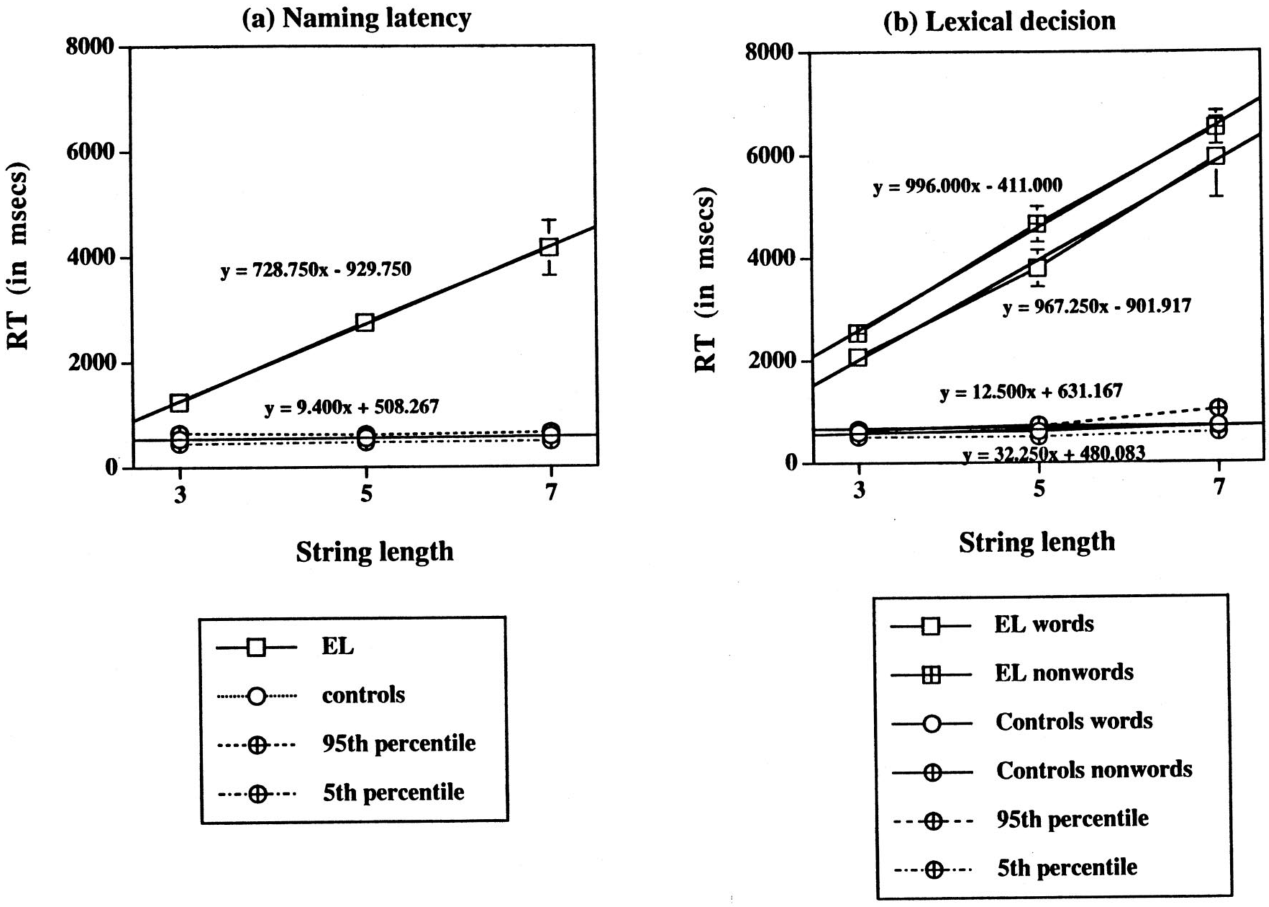

Fig. 2. Mean (a) naming and (b) lexical decision latency as a function of string length for EL and the matched controls along with the SE bars. The SE bars for the control subjects are not apparent because of the scale of y-axis. The intercepts and slopes calculated from the regression analyses are included.

($F(1,101) = 499.5$, $P < 0.0001$), with EL responding slower than the controls, and for length, ($F(2,101) = 48.9$, $P < 0.0001$), with slower responses as string length increased.

A comparison of the naming latency and lexical decision data (words only) for EL in an ANOVA with task (naming latency/lexical decision) and word length, with RT as the dependent measure, confirmed the significant effect of word length, ($F(2,101) = 623.7$, $P < 0.0001$). An effect of task was also evident, ($F(1,101) = 7.3$, $P < 0.01$), with slower base RTs overall in lexical decision ($M = 3957$ ms) than in naming ($M = 2715$ ms) as can be seen in Fig. 2. Importantly, there is no interaction of length and task, ($F(2,101) = 1.09$, $P > 0.1$), suggesting an equivalent effect of string length across both tasks.

These findings confirm the diagnosis of LBL reading for patient EL. Whereas the control subjects show small but significant effects of word length, consistent with data previously reported in the literature [76], EL shows a dramatic change in performance as a function of string length for naming latency, under both unlimited and brief exposure, and for lexical decision. In comparison with other LBL patients, EL falls within the moderate range although her accuracy is particularly good (see [68] for tabulation of severity in RT and errors).

Letter identification as a function of serial position. One of the hallmark features of LBL readers is that they show abnormal letter identification when required to detect whether a target is present in a random letter string. When identification accuracy is plotted as a function of the target's serial position in the string, normal subjects typically show a W-shaped curve (and a corresponding M-shaped curve in RT; [47]). In contrast, many, although not all [12, 65], LBL readers show a linear curve with detection falling off as the target occurs closer to the end of the string [5, 36, 38].

Apparatus and materials. To verify that EL shows the pattern commonly associated with LBL readers, in this experiment, a single target letter appeared on the left of the screen (three characters spaces from fixation) for 240 ms, following the presentation of a 500 ms foveal fixation point. After a 500 ms interval, a string of five random letters appeared for an unlimited duration, centered over the position of the previous target, with the final letter immediately next to fixation. For example, the target "V" appeared followed by the string "PSXVL". EL was required to decide whether the target was present in the string and to indicate her response using the right button. No response was necessary for target absent trials. The target was present in 100 (of 150) trials with equal sampling of 20 trials in each of the five serial positions. The visual angle subtended by the entire string was 3.6°. Both accuracy and RT to detect the presence of the target as a function of position was measured. Data from a previous control subject (who is also well matched with EL), taken from [6], was used for the purposes of comparison.

Results and discussion. EL made two errors, failing to detect the presence of the target once each in position 2 and 3. She correctly withheld her response on all absent trials. The control subject made no errors. The RT data from the control subject and from EL are shown in Fig. 3 with RT as a function of serial position in the string. The 5th and 95th percentile values for the control subject are also shown. As expected, the control subject shows the predicted M-shaped curve with relatively better detection in the middle and outer positions. In contrast, although EL performs as well as the control in positions 1 and 2, she shows a linear increase in RT as a function of serial position, ($F(4,93) = 24.2$, $P < 0.001$). Pairwise *t*-tests of EL's data across the different positions revealed significant differences between all positions except for the second and third positions. EL's increase in detection time towards the end of the string is consistent with a pattern of sequential processing starting from the left and moving rightwards and further confirms her diagnosis as a LBL reader.

Perceptual fluency. Having established that EL shows the hallmark characteristics of LBL reading, we can now go on to examine other aspects of her visual processing. Perceptual fluency is a measure that has been shown to be sensitive to detecting perceptual deficits in LBL [30, 67]. LBL patients typically perform well below the normative data on a series of pencil-and-paper perceptual fluency tests, taken from the *Kit of Factor-Referenced Cognitive Tests* [26].

Apparatus and materials. Three perceptual fluency subtests were administered and scored according to the standardized instructions, and timing was carried out with a hand-held stopwatch. The three tests all required that EL process visual stimuli under time pressure after some practice with the stimulus set. For the findings A's subtest, EL was instructed to mark any word containing the letter "a" where there were five target words and 16 distractors in a single column and each page had five columns. After a practice set of 63 trials, EL had 2 min to complete the test. The test was repeated after a short break and the final score for this section was the mean number of words correctly marked averaged across the two blocks.

In the Number Comparison subtest, pairs of digit strings, ranging from two to thirteen digits in length, were presented. A single page consisted of two columns of forty-eight pairs of number strings, for example: "4714306—4715306". EL was instructed to make a mark between the pairs of digit strings that were different and was given 90 s to complete each of two blocks with a short break between the blocks. The dependent measure was the number correct minus the number incorrect and a mean was calculated across the two blocks.

Finally, for the identical pictures task, each trial consisted of five shapes in a row, with a cue in the leftmost position and one target and three distractor shapes on the right. The position of the target varied across the distractor positions. Forty-eight experimental trials appeared in each of two blocks for a total of 96 trials and

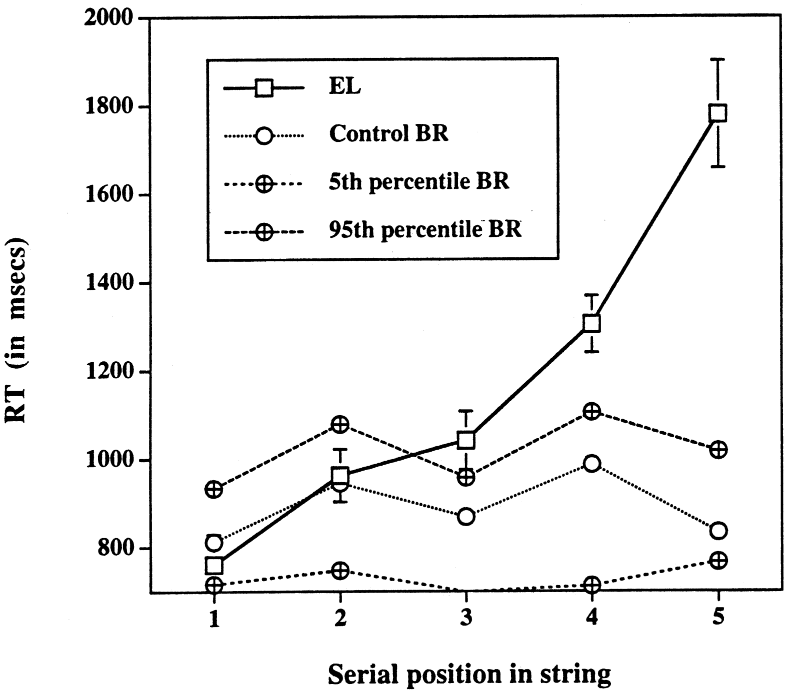

Fig. 3. Mean RT and SE bars for correct detection as a function of serial position for EL and a control subject, BR (taken from [5]). The SE bars for the control subject are not apparent because of the scale of y-axis.

90 s were given for each block. EL was required to mark the target object, which was the shape that most closely resembled the cue.

Results and discussion. EL performed poorly relative to the normative data. For the findings A's test, she obtained a score of 12, 2.64 SDs below the mean of 54.3 (SD = 14.9) for female college students and for the number comparison test, she obtained a score of 12, 3.04 SDs below the mean of 26.6 (SD = 4.8) for college males (no female norms are available). Finally, for the picture identification test, she scored 41, 1.56 SDs below the mean 56.7, (SD = 10.2) of college female students. While her scores are not as bad as those of some other LBL readers [67], her performance is still well below the normal limit. This series of three tests, one of which includes non-orthographic stimuli, suggests that EL has slowed or impaired processing on speeded perceptual tasks with non-orthographic as well as orthographic materials.

Picture identification

Having confirmed that EL fits the diagnosis of a LBL reader, the following experiment is the critical test of whether EL's perceptual difficulties extend to picture recognition. We were particularly interested in the effect of visual complexity of the stimulus and predicted that performance would be disproportionately worse for EL than for the control subjects as objects increased in visual complexity. However, because visual complexity is usually affected by the familiarity of the stimulus, we included familiarity as another important initial variable in the analysis.

Stimuli and apparatus. EL and the two control subjects, AS and JD, were presented with 255 of the 260 pictures from the Snodgrass and Vanderwart [71] set for naming (the remaining five items were unclear when magnified). The black-and-white line drawings were scanned into the computer from the original articles and magnified roughly 350%. Thus, the picture of the ruler (No. 192), for example, was 9.2 cm long and subtended a visual angle of 11.7°. Each picture appeared to the left of fixation where the center of the picture was offset by 10% of the screen width to the left of fixation. The pictures appeared for an unlimited exposure duration and the subject was required to name the picture. Both RT and accuracy were recorded. Whereas the control subjects completed all pictures in a single session, EL completed the set in two sessions, a week apart. First responses only were accepted.

Results and discussion. EL made three identification errors (TOE -> "thumb"; NAIL -> "bat, no, a nail" and JACKET->"blouse") and there were two further microphone errors (leaving 250 pictures for analysis). On two more trials, EL responded with slightly different labels than expected (e.g. GORILLA -> "ape" and SHEEP -> "lamb") but we considered these to be acceptable responses. Across the controls, there were seven misidentifications and 18 technical errors. Because both visual complexity and familiarity are continuous variables (with the values taken from [71], although see [45] for alternative coding schemes), we performed a regression analysis with these two variables and correct RT and we included the data from each of the two control subjects separately. The regression analysis revealed a significant difference in identification times between EL and the two control subjects ($F(1{,}690) = 7.05$, $P < 0.01$). There were also significant effects of familiarity, ($F(1{,}690) = 8.52$, $P < 0.01$) and of visual complexity, ($F(1{,}690) = 6.15$, $P < 0.05$) as well as combined effects of group with familiarity, ($F(1{,}690) = 4.9$, $P < 0.05$) and of group with visual complexity, ($F(1{,}690) = 4.8$, $P < 0.05$). The two-way interactions emerge from the fact that there is a disproportionate increase in EL's RTs relative to the controls both as familiarity decreases and visual complexity increases. Both familiarity and visual complexity jointly interact with group, ($F(1{,}690) = 5.03$, $P < 0.05$).

To illustrate these results graphically, we arbitrarily divided the complexity data into three classes, low, medium and high, and have plotted RTs for these complexity classes as a function of familiarity for EL and the controls in Fig. 4. As can be seen from this figure, there is a negligible effect of visual complexity for the control subjects in highly familiar items with a somewhat greater effect on RT with low familiar items. EL's data, however, reflect a greater sensitivity to the effect of familiarity with far slower times for low than highly familiar items. The effect of visual complexity is particularly evident in the difference between low and medium items but the effect is somewhat obscured by the anomalous mean for low familiarity, high complexity items. This last data point is perhaps a less reliable estimate of EL's performance as there are only 17 values in that cell (for the controls, because there are two subjects and hence 34 trials, the mean may be more stable than is the case for EL). Aside from this quirk, these findings suggest that the visual complexity of a stimulus is a significant determinant of EL's object identification performance and this is more pronounced for items that are less familiar to her.

There are, however, a whole range of psycholinguistic variables which affect the naming times of both normal subjects as well as patients with aphasia including phoneme length of the stimulus, age-of-acquisition (AoA), frequency and imageability [49–52]. To examine whether any of these variables contribute significantly to the RTs, we first performed a simple regression analysis separately on the data for EL for phoneme length, AoA (both objective and rated AoA; [49]) and frequency and imageability [49]. Only phoneme length was a significant determinant of RT for EL. We thus performed another regression on EL's data including visual complexity and familiarity, as we had done before, but this time included phoneme length to examine whether there was still an effect of the critical variables, complexity and familiarity, once phoneme length was partialled out. There was a significant three-way interaction between complexity, familiarity and phoneme length, ($F(1{,}210) = 8.1$, $P < 0.01$) and the variance accounted for by this model was 35%. When the effect of phoneme length was partialled out,

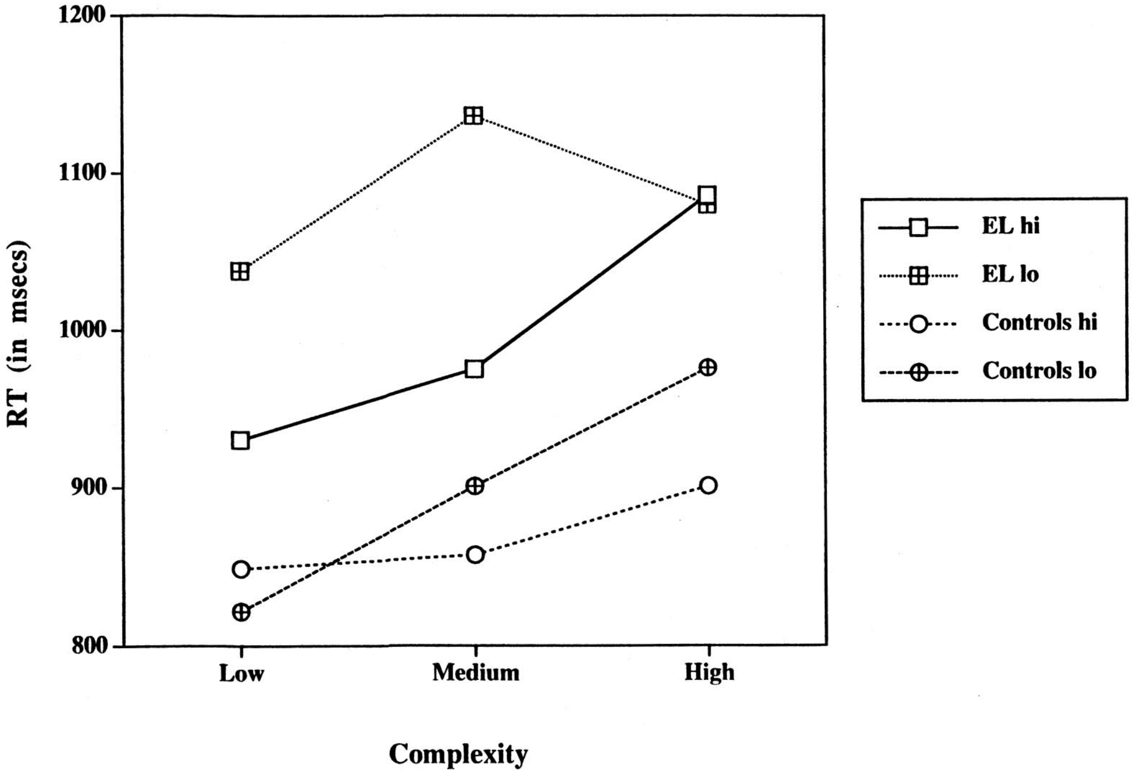

Fig. 4. Mean RT in picture identification for EL and the two control subjects for Low, Medium and High complexity items as a function of familiarity.

there was still a significant two-way interaction of familiarity and complexity (as reported above) and the variance accounted for, 23%, was still high. These findings suggest that although some other variables might influence the pattern of RTs, familiarity and complexity are still important determinants of performance.

Section 2: Picture Identification in a Group of LBL Readers

In Section 1 we demonstrated that EL, a LBL reader with no overtly obvious perceptual or object recognition deficits as shown in good performance on the VOSP and minimal errors in object naming, is significantly impaired relative to controls when evaluated with more stringent measures of visual processing (perceptual fluency and visual complexity of objects). What remains unclear is whether this finding is restricted to EL (for example, because her lesion extends somewhat more anterior than is the case with some other LBL patients) and is perhaps unrelated to LBL *per se* or whether a similar pattern would be obtained in other LBL readers. In addition, although the data from EL shown in Fig. 4 support the finding of a disproportionate effect on RT as a function of complexity and familiarity, her performance on the high complexity, low familiarity objects is not as clear as one might have expected. In this next experiment, then, we examined the picture recognition abilities of a larger group of LBL readers with pictures of low and high complexity. Instead of using the entire set of 260 pictures, however, we subselected an equal number of items of high and low complexity.

Description of subjects

Five new LBL readers are included in this analysis. Detailed biographical data and details of the reading performance of these patients are included in a separate article and the reader is referred to that article for further description of the subjects [7]. All subjects are right-handed and native speakers of English. Biographical information and anatomical details of their lesions are provided in Table 1. Three of the subjects (DS, MW and MA) participated in a previous study [67] and were impaired, relative to normal subjects, on a number of different tests of perceptual function, including those that measure perceptual fluency, as described above.

All subjects had previously read several lists of words containing three-, five- and seven-letter items and naming latency and accuracy were recorded [7]. The procedure followed was identical to that described previously for EL and the naming latencies obtained are plotted as a function of word length for each subject individually in Fig. 5. As is evident from this figure, all five subjects show the hallmark increase in naming latency as a function of word length and are thus classifiable as LBL readers. The values of the intercept and slopes obtained from a regression analysis with reaction time set against word length are shown next to each subject's graph line. The patients differ in the severity of the reading impairment but even the mildest patient DS, who is more than 10 years post-stroke, still has a slope of 97 ms, three times longer than that usually obtained for normal subjects under similar testing conditions [13, 76].

The control subjects were recruited from the normal volunteer pool at the Rotman Research Institute of Baycrest Center, Toronto. No subject had any previous history of neurological disease and all were right-handed and with normal or corrected-to-normal visual acuity. Control subjects were matched in age and gender to each of the LBL readers.

Picture identification in five LBL readers

Stimuli and procedure. To test the picture identification of these five patients, a procedure similar to that used with EL was adopted with a few exceptions. Because all of the subjects

Table 1. Biographical and lesion details of the five LBL readers

Pt.	Age*	Etiology	CT Scan results	Other relevant behaviors
DS	37	Posterior cerebral artery occlusion; migrainous	L occipital infarction	Right upper quadrantanopia
MW	67	Infarction	L occipital infarction	Right homonymous hemianopia; ensuing depression
DK	65	Posterior cerebral artery infarction and mass effect	L occipital lobe infarction	Right homonymous hemianopia
MA	37	Closed head injury	no focal CT lesion; bilat. frontal slowing EEG	Right homonymous hemianopia; surface dysgraphia
IS	46	Posterior cerebral artery infarction	L occipital-temporal region including hippocampus, fusiform and lingual gyri	Right upper quadrantanopia; mild memory deficit; surface dysgraphia

* Age refers to the age at which the initial testing took place.
Some patients have participated in subsequent follow-up studies and the age of testing is then obviously different.

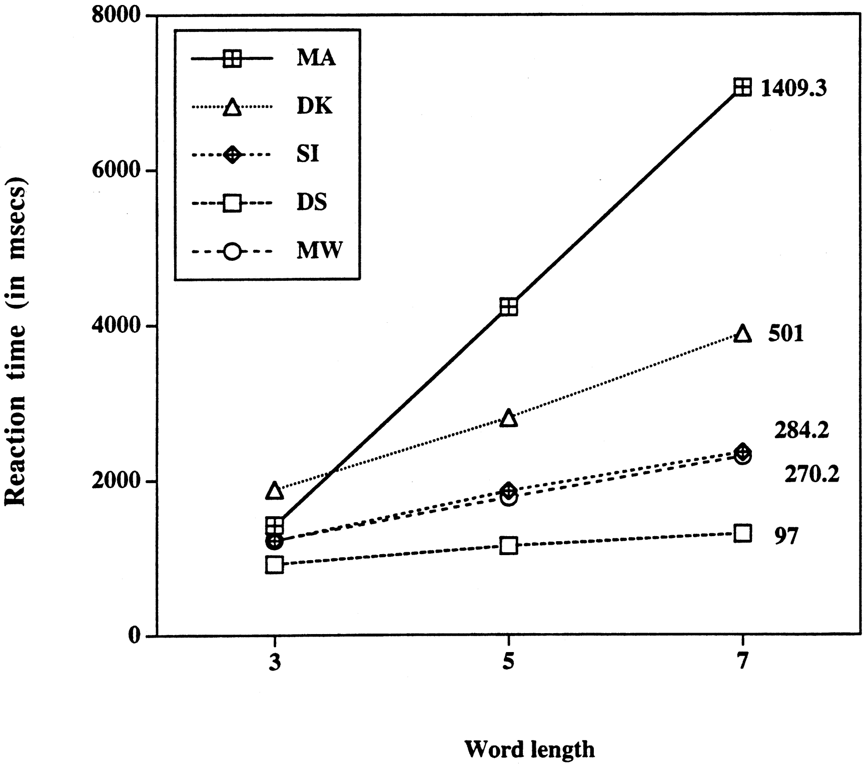

Fig. 5. Mean RT in naming words as a function of string length for the five LBL readers plotted individually.

had a right visual field defect, a frequent concomitant of LBL, we presented half the items to their intact left visual field and half in the foveal position. In addition, instead of having subjects identify all 260 pictures from the S&V set, we selected a set of 40 low- and 40 high-complexity items and field of presentation was orthogonally crossed with complexity. The items used in this experiment are listed in Appendix 1 and are listed, where available, with their age-of-acquisition values [49], number of phonemes and visual complexity and familiarity values from the S&V list. The means (and standard deviations) of the complexity values for the four subsets of items are: central presentation high complexity 4.3 (0.29), central presentation low complexity 1.8 (0.43), left presentation high complexity 4.3 (0.21), left presentation low complexity 1.8 (0.35). For each subject, data were collected from one pairwise age- and gender-matched non-neurological control subject using the identical procedures. All subjects named the pictures presented as rapidly as possible and RT and accuracy were measured.

Results and discussion. A total of 1.8 and 2.1% of trials were removed from the patients and control subjects, respectively, because of technical difficulties (false start, microphone failure). The patients made an average of 4.2% errors and the controls 2.6% errors. An ANOVA on the errors using group as a between-subjects factor and visual complexity (high/low) and position of presentation (left of fixation/central) as within-subject factors revealed no differences between the two groups whatsoever and no interaction with either complexity or field of presentation (all $P > 0.05$).

Using only the correct trials, reaction times that exceeded the mean of a cell by more than two standard deviations were removed. Based on this, a further 4.9 and 6.2% of the data were removed for the patients and controls, respectively. To examine the effect of visual complexity on picture identification, we performed an ANOVA including group (controls/patients) as a between-subject factor and visual complexity (high/low), position (left of fixation/central) and familiarity (high-/low) as within-subject factors, and RT as the dependent measure. Although this experiment was not designed so that familiarity was perfectly crossed with complexity and position, we included familiarity as a variable given that it had influenced EL's identification RTs and had interacted with complexity in the previous experiment. The important finding was that although familiarity affected RTs significantly, ($F(1,8) = 6.34$, $P < 0.05$), it did so equally for the control subjects and patients and did not interact with any of the other variables.

Because familiarity did not affect the two groups differently either alone or jointly with any other variables, we re-analysed the data excluding familiarity and using only the orthogonally crossed within-subject factors of complexity and position with group as the between-subject factor. There was a significant difference in RT between the groups, ($F(1,8) = 18.4$, $P < 0.005$), with the patients' RT being, on average, 595 ms slower than the control subjects. Collapsed across groups, there was a clear effect of visual complexity, ($F(1,8) = 15.7$, $P < 0.01$), with a 118 ms difference between high and low complexity items and of position, ($F(1,8) = 11.2$, $P < 0.01$), with RTs to central targets 136 ms slower than to left targets. There was a trend in the two-way interaction with the control group less affected by the position of the stimulus than the patients, ($F(1,8) = 4.2$, $P = 0.07$); the difference between central and lateral presentation was 58 ms for the controls and 256 ms for the patients. The other trend, also in the correct direction, was for the groups to be differentially affected by complexity, ($F(1,8) = 3.9$, $P = 0.08$), with a 95 ms and a 282 ms slowing for high- over low-complexity items for the controls and patients, respectively.

There was also a significant interaction between complexity and position, ($F(1,8) = 8.4$, $P = 0.01$). A decomposition of this interaction using Tukey post-hoc tests (with $P < 0.05$) shows that there was only a difference between high and low complexity items in the central presentation but not in the left presentation. This affected the two groups equally, as reflected in the absence of a significant three-way interaction ($F(1,8) = 4.1$, $P > 0.05$). The absence of a complexity effect for items on the left, even in the control group is puzzling and might simply have to do with the way the pictures were sampled in this particular experiment; the subjects (controls and patients with the exception of patient, WM, see below) saw the same 40 pictures presented to the left and the same 40 presented to the center (what we will term "the standard assignment"). An obvious explanation for the lack of a complexity effect on the left, then, is that the particular items presented to the left were simply not sufficiently sensitive to pick up any existing differences in performance even though the rated complexity values of the two sets of items were ostensibly equivalent. If this is indeed the explanation and the absence of a complexity effect on the left is merely an artifact of sampling rather than an effect of position of presentation, then we should expect to see a complexity effect when we reverse the positions of presentation. Thus, when we reverse the lists and present on the left those items that had previously appeared in the center and produced the complexity effect and present to the center those items that were previously on the left and did not yield the complexity effect, we should see the complexity effect on the left now and not in the center. If this turns out to be the case, then we will be justified in analysing the differences in patient and control performance only on those items that produce the complexity effect i.e. the central items.

In a separate experiment,* we verified the sampling artifact with a group of young undergraduate control subjects by first replicating the experiment using the standard assignment of items as described above on half the group and then by reversing the lists in the second half of the group so that the items presented centrally previously were now presented to the left and vice versa. The most important finding from this analysis was that, when the standard assignment was used, a complexity effect was obtained in the center but not on the left, replicating our previous result, but when the lists were reversed, a complexity effect was now obtained only for items on the left and not for items in the center. These findings suggest that an unforeseen and unexpected confound in the sampling procedure biases the findings so that only a subset of the items produce a complexity effect in normals. We then consider in our comparison of the LBL readers and their controls only those items that are sufficiently sensitive to produce a complexity effect.

The comparison below includes only those data from the central presentation (since this is where the normal elderly subjects showed the complexity effect) and examines the group differences on these items alone. The findings for central items as a function of high- and low-visual complexity for the two groups are presented in Fig. 6 and Tukey post-hoc tests are used to examine pairwise differences. The 5th and 95th percentile values are also shown for the control subjects.

As is evident from this figure, the normal controls show the expected difference between high and low-complexity items, reporting high complexity items 152 ms slower than low complexity items. The patients, however, show a disproportionate increase in RTs for high-complexity items with a 529.6 ms difference between the high and low items, roughly four times that of the normal value. These data suggest a disproportionate influence of complexity on the patients relative to the controls. This point is also evident from examining the percentile boundaries for the control subjects. Whereas the mean RT for the low complexity items for the patients fall within the distribution of the normal subjects, this is not the case for the high complexity items.

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* In this experiment, we tested 20 undergraduate subjects with a mean age of 19.7 ($r = 17$–22), 14 of whom were male and six female. Subjects were drawn from the undergraduate psychology pool at Carnegie Mellon University and participated for course credit. One subject was left-handed and the rest were all right-handed. All had normal or corrected-to-normal visual acuity. All subjects named the same 80 pictures as the patients and their controls, half of which were presented to the left and half to the central position, with complexity as an orthogonal variable. One group of subjects saw the identical pictures as the patients and controls presented in the center or on the left ('standard" assignment) and the other group had the lists reversed i.e. saw those "central" items on the left and the "left" items on the right ("reverse" assignment). A total of 18.8% of the trials was removed from the analysis, 6.25% being microphone or technical errors, 6.8% as misnaming (or very uncommon names) and the remaining 5.8% as outliers. An analysis was performed on correct RTs with complexity and familiarity as within-subject variables but list assignment as a between-subject variable. For the present purposes, only two findings are significant. There was a significant two-way interaction between position and list-assignment so that RTs to the standard items in the center and to the reverse items on the left (i.e. these are identical lists) were both slower than the standard items on the left and reverse items in the center (again, these are identical lists), ($F(1,18) = 9.8$, $P > 0.01$). Of even more relevance is the three-way interaction with complexity, ($F(1,18) = 11.6$, $P > 0.01$), in which we see, in the standard list, the same two-way interaction as observed previously with a significant difference in complexity only for central but not for left-sided items. In the reverse list, we see the opposite result with a complexity effect only on the left and not in the center. These findings suggest that the items that made up the central standard presentation are robust in yielding a complexity effect and further analysis should be done only on these items.

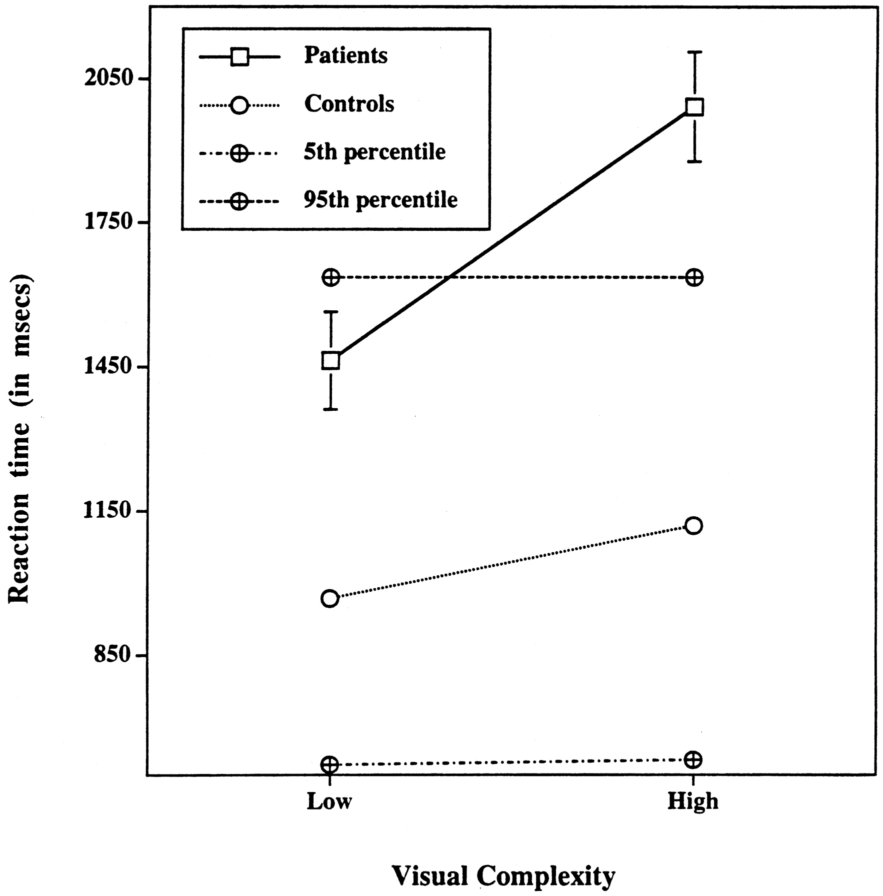

Fig. 6. Mean RT for the five patients and the five control subjects in the picture identification task plotted as a function of visual complexity (centrally-presented items only). The 5th and 95th percentile values for the control subjects are also plotted. The SE bars for the patients are visible but not for the controls given the extent of the y-axis.

To examine the effect of complexity on each subject individually, we ran a second ANOVA by decomposing the averaged patient data presented in Fig. 6 and rerunning the ANOVA with complexity and position as within-subject variables and by including subject as a between-subject factor. Even though only the central position appears to yield meaningful results, we decided not to exclude the left position as more subtle interactions might become evident in individual subjects. As expected, we see the three-way interaction between subjects × position × complexity, ($F(4,241) = 3.5$, $P < 0.001$), with minimal differences between high- and low-complexity RTs for items presented to the left and rather larger differences for items presented centrally, although the extent of the difference varied across subjects. The ANOVA also revealed a significant main effect of subject, ($F(4,241) = 12.6$, $P < 0.0001$), indicating individual base RT differences among the subjects. Collapsed across subjects, there is also a main effect of complexity, ($F(1,241) = 12.6$, $P < 0.0005$), as might be expected from the previous analysis, and an interaction of complexity by subject, ($F(4,241) = 30.1$, $P < 0.0001$). These individual differences as a function of visual complexity for the centrally-presented items only are shown in Fig. 7. The averaged mean of the RTs across the control subjects is also shown.

As is apparent from Fig. 7, the individual subjects show a difference between high- and low-complexity items albeit to differing degrees. Whereas the difference is particularly striking in patients MA, DK, IS and DS, it is only 36 ms in patient MW for the central items. Unlike the other subjects, MW received the reverse assignment (items presented centrally to others were presented to his left and vice versa). The absence of a significant effect centrally for MW might thus be attributable to the fact that he received the less sensitive items in the central position. When we examine his performance on the more sensitive items, however, i.e. those presented to his left, however, we still do not see a significant complexity effect. On an ANOVA with just the data from MW, there is neither an effect of complexity, nor of position nor an interaction (all $F > 1$), in contrast with the other four subjects. It appears, therefore, that MW is not affected by the complexity of the pictures. A possible explanation for the difference in MW's performance is that he has less data than any of the other subjects; through a combination of microphone errors and misnaming, his sample is relatively small (only 50 of the total 80 items) and

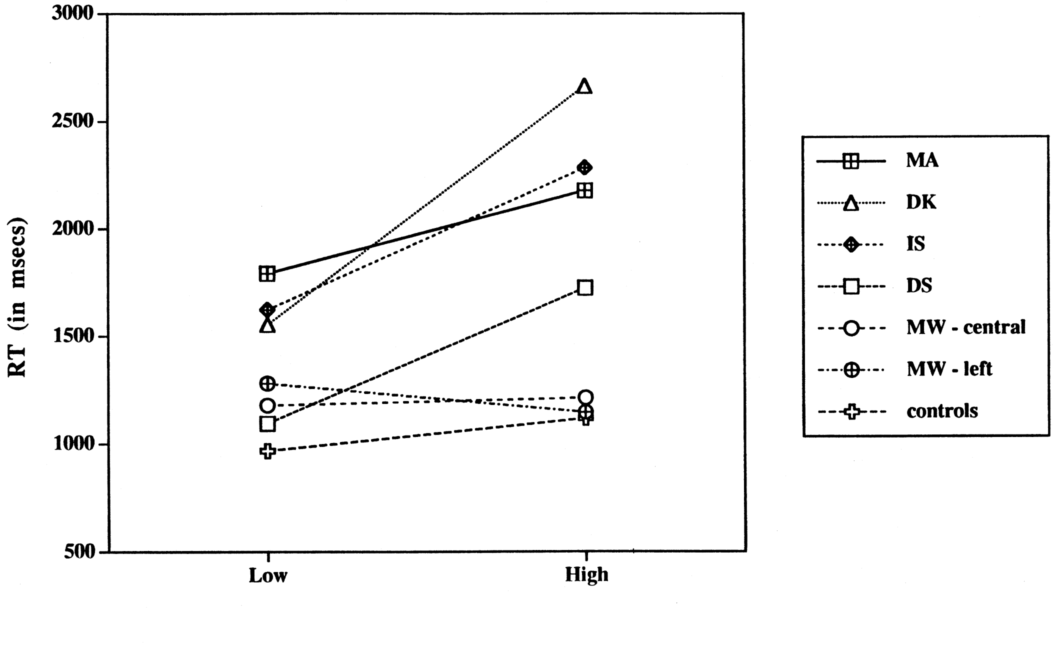

Fig. 7. Mean RT for identifying pictures as a function of visual complexity plotted for five LBL readers individually, and the means of the controls plotted for easy comparison.

the absence of a complexity effect may partly be due to a reduction of statistical power in the analysis. This explanation, however, is speculative and further work with other LBL patients is necessary to determine whether there are indeed differences between individual patients on this dimension.

Taken together, these data suggest that the majority, if not all, of patients with LBL reading are also relatively impaired at object recognition, in comparison with normal subjects, as manifest in the disproportionate increase in RT as visual complexity increases.

General discussion

The purpose of this study was to examine the extent to which "pure alexia" is really pure. Pure alexia is a neuropsychological deficit that is often considered to be the quintessential case of a subsystem that is isolable in the mental architecture. Evidence to support this claim is that, following damage to a brain region, usually localized to the inferior occipital or occipitotemporal region of the dominant hemisphere [22, 23], one observes what appears to be a domain-specific deficit limited to the processing of alphanumeric stimuli [24, 33]. Pure alexia may also be observed when this critical region is rendered inaccessible following, for example, damage to subcortical sites (for example, [1, 21, 70]). Although there is some variability in the extent to which both letters and numbers are affected in pure alexia [64], the deficit appears to be particularly evident with alphanumeric symbols. When other neurobehavioral deficits co-occur with pure alexia, they are either mild or arise from the fact that the lesion is large and extends beyond the left occipital region [22].

The primary emphasis of studies conducted with pure alexic patients to date has been on their reading performance, known as letter-by-letter reading because of the hallmark word length effect [56]. In contrast, rather little attention has been paid to the extent to which these patients might have a more fundamental perceptual deficit, of which pure alexia may be one manifestation. We have argued that because reading is a relatively new cognitive ability, it is likely that it is mediated by a neural substrate that subserves other visuoperceptual functions and that this general purpose system has recently been recruited to mediate the processing of alphanumeric symbols. Therefore, we predicted that, under stringent testing conditions or with sufficiently complex stimuli, one might uncover a more pervasive perceptual deficit in pure alexic patients than has often been presumed (but see [30, 31, 41]).

In this article, in the first section, we show that a single patient, EL, who exhibits the signature pattern of pure alexia, is impaired, relative to normal subjects, in the identification of black-and-white line drawings of objects. Although EL is accurate, her naming performance is disproportionately slowed (as measured in RT) as a function of the visual complexity of the stimulus. EL also performed well below normal on tests of perceptual fluency which have been used previously to demonstrate a perceptual deficit in pure alexic patients [30, 67]. We verified our findings in the second section of this article with a group of five LBL readers and showed that they too are more impaired at identifying high- vs low-complexity pictures, relative to the control group. Aside from a single patient (MW) who does not appear to follow this pattern (although this may be for artifactual reasons as we point out in our analysis), the remaining four patients are all significantly slower than the control subjects in identifying the more complex pictures. These findings are compatible with the few existing studies [30, 42, 67] that have argued for a more fundamental perceptual problem which gives rise to LBL reading but which may also impair picture processing [31].

We have argued that the observed association between a reading deficit and a more general perceptual problem arises from a lesion to a common underlying system. There is, however, a simple alternative explanation and that is that these patients have suffered more extensive brain damage and that the lesion implicates additional areas (perhaps in inferior temporal cortex) that mediate picture recognition. We think this alternative is highly unlikely. We have shown that a fairly large number of LBL patients show the association in their reading and object recognition performance. It is unlikely that all of these patients have extensive lesions and we know, in some cases, that the lesion is rather circumscribed [5, 8]. Based on this, we favour the explanation that the deficit in other domains of perceptual processing along with the reading deficit reflects damage to a more general system that is involved in many aspects of visual processing.

These findings challenge the traditional view that pure alexia is a "pure" deficit and instead suggest that, like a number of other forms of acquired dyslexia [53], pure alexia emerges from a disorder to a more general-purpose cognitive mechanism. The question then is, why is it that we observe a rather more severe and florid deficit in reading in these patients who are not obviously agnosic, manage to negotiate their way in the world easily and whose main complaint is often just an impairment in reading. One possible explanation for this discrepancy concerns differences between reading and other forms of visual processing. One version of this explanation claims that there is a quantitative difference between reading and object processing and that reading is a particularly demanding task, taxing the perceptual system far more than other forms of visual processing. The other version argues that the discrepancy arises from a qualitative difference in the types of visual processing required for word and object processing. We consider each of these below.

Friedman and Alexander [31] explain the disproportionate impairment in their pure alexic patient in a quantitative way. They attributed LBL not to an elementary visual perceptual problem *per se* but rather to a problem in the automatic identification of visual input. This identification problem, however, manifests more in reading than in other domains because in reading, attention must be focused on each letter and this is laborious and difficult. On the other hand, if an object or picture is not identified automatically, the consequences are minor in most circumstances and thus the underlying deficit has its greatest impact in the domain of reading. This quantitative difference in processing demands for reading and object processing, however, is likely not the optimal explanation given that there have been reports of cases who are impaired at (on this account) the supposedly simpler object processing while retaining the ability to do the supposedly more difficult word reading (see, amongst others, [3, 34]).

Qualitative differences between object and word processing may then provide a better account of the findings. Farah [27, 28], for example, has suggested that reading depends heavily on the ability to represent multiple parts and, although this ability is not exclusive to the orthographic domain, there is differential reliance on this part-based processing for word reading. Although some aspects of this hypothesis have been challenged and the extent to which the deficit affects part-decomposition and representation *per se* is unclear [67], the claim that there might be differential but not exclusive reliance for the processing of some types of stimuli over others seems entirely plausible.

The notion of differential reliance on parts of a single system for particular types of processing is generally referred to as functional specialization. Rather than claiming that specialization is physically instantiated or hardwired in a modular fashion in the brain, some have argued that specialization might be profitably thought of as a process in which, for example, there is differential reliance on some aspects of processing for certain classes of stimuli [68]. Thus, instead of postulating distinct *a priori* divisions with orthographic stimuli represented separately from other forms of visual stimuli, a feasible alternative is that, within the same general distributed subsystem, words might be somewhat more dependent on some processes than others. For example, there are considerably more perceptual cues such as depth, color, luminance and other surface information that potentially contribute to and constrain object recognition compared with word recognition. In contrast, letter recognition relies strongly and almost exclusively on feature and edge detection (and perhaps part decomposition [27]) in the early stages of visual processing although at later stages, contextual effects and higher-order knowledge can certainly make a contribution. The difference between objects and words, then, is not to be found in the structure of the system *per se* but rather in its functional and adaptive properties and requirements.

How might such functional specialization come about? A particularly compelling explanation is provided by computational simulations that show that, with minimal assumptions about the innate structure of a system, experience-dependent processes play a critical role in determining a brain region's functional properties [39, 60, 62, 66]. Given minimal starting assumptions about structure-function correspondences in the brain (such as different patterns of connectivity between neurons, bias towards short connections), it is possible to observe the emergence of some functional specialization in a system that develops, learns and gains experience.

We have presented thus far what appears to be a dichotomy between dedicated systems and systems that are general-purpose and, based on our findings, have argued in favour of the latter. There is, however, an intermediate solution which might also potentially explain our findings and which incorporates some functional specialization within the context of a general-purpose system. On this account, over the course of time and experience, even within a general-purpose system, regions within the computational space could develop greater weightings with regard to different materials [60, 62]. Damage to these regions will lead to very poor performance on alphanumeric tasks, but as these regions are involved with general object processing too, the pure alexic patients will have measurable object recognition deficits as well. Particularly pertinent to the data reported here is that such an account has been demonstrated in the context of a unitary neural network that can self-organize stimuli from seemingly arbitrary categories (letters or numbers) and become somewhat spatially segregated. Using a Kohonen network [43] in which Hebbian learning drives the correlations between stimuli and letters tend to co-occur with other letters temporally, Polk and Farah [63] showed that the network exploits these temporal correlations and that through short-range excitatory connections, some differential weighting (and to some extent, some differential segregation) may be obtained within a distributed system. The critical point is that within a unitary, general-purpose system that serves fundamental cognitive operations, functional specialization and differential reliance may be possible. Whether this is the way in which reading comes to be functionally specialized in humans within a general-purpose system that likely evolved to accomplish more basic perceptual operations, remains to be verified.

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Appendix 1

Item	Position	Age of Acq (months, 75% rule, Morrison et al)	Visual complexity (S&V)	Familiarity (S&V)	Phoneme Length
cow	center	23.4	3.85	2.42	2
house	center	22.1	3.9	3.72	3
ant	center	62.5	3.92	2.62	3
cannon	center	114.5	3.92	1.52	5
fly	center	56.5	4.1	2.45	3
elephant	center	23.4	4.12	2.35	7
rooster (cockerel)*	center	74.5	4.12	4.68	6
rhinoceros	center	86.5	4.15	3.46	9
celery	center	140	4.25	3.4	6
spinning wheel	center		4.25	2.8	9
leopard	center	68.5	4.28	4.2	6
french horn	center		4.3	4.78	9
pineapple	center	74.5	4.35	4.78	7
grasshopper	center		4.4	2.05	9
lobster	center	86.5	4.48	4.18	7
windmill	center	50.5	4.62	3.48	7
accordian	center		4.68	2.15	8
skunk	center	140	4.72	1.5	5

bee	center	56.5	4.75	2.68	2
peacock	center	92.5	4.75	3.34	5
heart	center	50.5	1	4.52	4
arrow	center	62.5	1.05	3.38	3
star	center	38.5	1.05	4.52	4
box	center	38.5	1.38	2.88	3
skirt	center	56.5	1.4	3.42	5
envelope	center	68.5	1.42	4.12	7
balloon	center	22.1	1.55	2.58	5
needle	center	86.5	1.55	2.45	4
nail	center	68.5	1.8	3.98	3
lips	center	50.5	1.85	3.42	4
wine glass	center		1.85	2.5	7
frying pan	center		2.05	2	8
book	center	22.1	2.1	4.75	3
orange	center	38.5	2.12	3.15	5
cap	center	68.5	2.18	3.12	3
pliers	center	126.5	2.2	2.92	6
potato	center	74.5	2.2	2.9	6
cigarette	center	86.5	2.25	3.65	7
nut	center	114.5	2.3	2.88	3
thumb	center	38.5	2.38	2.72	3
kangaroo	left	44.5	3.98	3.65	7
fox	left	38.5	4.02	3.15	4
car	left	22.1	4.05	4.7	3
harp	left	126.5	4.05	3.48	4
alligator	left		4.08	1.65	8
rollerskate	left		4.08	2.2	9
flute	left	92.5	4.15	3.88	4
owl	left	38.5	4.22	3.4	2
butterfly	left	23.4	4.25	2.92	8
crown	left	56.5	4.25	1.52	4
basket	left	38.5	4.3	2.18	6
lion	left	23.4	4.3	1.92	4
train	left	25.1	4.32	4.72	4
raccoon	left	140	4.4	4.18	5
clown	left	38.5	4.5	2.6	4
seahorse	left	86.5	4.5	4.18	6
snake	left	25.1	4.52	4.56	4
zebra	left	44.5	4.55	2.72	5
piano	left	44.5	4.58	3	5
giraffe	left	38.5	4.65	4.15	5
moon	left	25.1	1.02	2.85	3
baseball bat (bat)	left	56.5	1.2	3.68	9
sun	left	23.4	1.2	4.02	3
cherry	left.	74.5	1.6	3.38	4
nose	left	56.5	1.6	4.4	3
bottle	left	38.5	1.68	3.72	5
necklace	left	50.5	1.78	2.7	6
ruler	left	62.5	1.85	1.52	5
flag	left	38.5	1.88	3.28	4
pipe	left	74.5	1.88	4.42	3
knife	left	23.4	1.92	3.8	3
tomato	left	68.5	1.98	4.8	6
button	left	38.5	2.02	3.85	4
spoon	left	22.1	2.02	1.9	4
wrench (spanner)	left	102.5	2.02	4.58	4
cloud	left	56.5	2.12	3.82	4
arm	left	38.5	2.15	4.75	3
ashtray	left	140	2.25	3.56	5
plug	left	68.5	2.25	3.42	4
glass	left	44.5	2.85	4.08	4

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* The item in brackets is the item for which the Age-of-Acquisition value was obtained from [47].