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PERCEPTUAL AND LEXICAL FACTORS IN A CASE OF LETTER-BY-LETTER READING

Doriana Chialant
University of Massachusetts at Amherst, and Tewksbury Hospital, MA, USA

Alfonso Caramazza
Harvard University, Cambridge, USA

We report the case of a letter-by-letter reader (MJ) who showed normal processing of single letters and who could normally access the orthographic input lexicon when presented with letter names for aural recognition, or when allowed enough time to process a visually presented letter string. However, MJ showed severe difficulties in simultaneously processing multiple letters and other simple visual stimuli. Furthermore, she does not have normal access to lexical orthographic representations and their meanings when stimuli are presented for too brief a time to allow for serial processing of the letter string. We found no evidence of (partial) lexical or semantic access without corresponding recognition of the letters in a word: No signs of implicit reading were observed when the input stimuli were controlled for the relevant visual features; "implicit reading" was only obtained under conditions that allowed sophisticated guessing. This pattern of results is interpreted as indicating that LBL reading (at least in MJ) results from damage to prelexical processing mechanisms. In MJ's case, the deficit reflects the degraded transfer of information from a normal visual processing system in the right hemisphere to a normal language processing system in the left hemisphere.

Requests for reprints should be addressed to Alfonso Caramazza, Department of Psychology, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA. Email: caram@wjh.harvard.edu

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INTRODUCTION

What is the nature of the damage such that reading becomes laborious, marked by a consistent word length effect, and apparently characterised by a letter-by-letter, serial processing of the input?

Letter-by-letter (LBL) reading, also known as "pure alexia[1]" or "alexia without agraphia," is a form of acquired dyslexia in which patients appear to read single words by identifying them one letter at a time, with the result that reading is characterised by a marked word length effect. There is great variability in the extent to which reading is slowed down in different patients (cf. case JG in Coslett & Saffran, 1989; case KC in Patterson & Kay, 1982; case BL in Friedman & Hadley, 1992; case RAV in Warrington & Shallice, 1980). This deficit occurs in the face of sparing of all other linguistic modalities and, in particular, of the ability to recognise orally spelled words and of the ability to write.

From a traditional neurological standpoint, LBL reading has been interpreted as a disconnection syndrome in which a right visual field cut prevents direct access to information in the left hemisphere, and damage to the splenium of the callosum alters interhemispheric transfer (Damasio & Damasio, 1986, Déjèrine, 1982; Geschwind, 1965; Greenblatt, 1973).

Since Déjèrine's (1892) first interpretation of this phenomenon as a disconnection syndrome between the occipital cortices and the left hemisphere's mechanisms that allow word recognition, LBL reading has been interpreted functionally in numerous ways. There are at least three distinct classes of interpretations. One class of interpretations views LBL reading as a low-level perceptual deficit that affects visual processing for linguistic and nonlinguistic stimuli alike (Friedman & Alexander, 1984; Rapp & Caramazza, 1991). A second class of interpretations views LBL reading as a deficit in letter recognition (Arguin & Bub, 1994, Howard, 1990). Finally, a third class of interpretations views LBL reading as a deficit at the word level (Bub, Black & Howell, 1989; Shallice & Saffran, 1986; Warrington & Shallice, 1980).

Patterson and Kay (1982) compared information from several clinical studies of LBL readers and concluded that the phonemenon is independent of: (a) hemianopsia, since there are LBL readers without visual field cuts, and hemianopic cases with reading impairments other than LBL reading (Greenblatt, 1973; Patterson & Kay, 1982); (b) simultanagnosia, since processing in free vision of complex pictures seems unaffected; (c) attention and short-term visual memory deficits, since these functions were good in at least some cases (Warrington & Shallice, 1980); and (d) decreased visual acuity, as this function was shown to be normal in a number of cases (Warrington & Shallice, 1980). The authors thus concluded that LBL reading does not result from a low-level visual

[1] Pure alexia is a broader category of reading disorders than LBL reading. It includes those cases in which patients are virtually incapable of reading any word (see Miozzo & Caramazza, this issue).

perceptual deficit. Later findings of implicit reading in some LBL cases (Coslett & Saffran, 1989, 1994a, 1994b) have also been interpreted as evidence against the perceptual deficit accounting of LBL reading.

More recently, testing of perceptual processing with limited exposures has shown that in some patients the deficit can extend to stimuli other than words, and may be affected by spatial and perceptual properties of the input (Farah & Wallace, 1991; Kay & Hanley, 1991; Rapp & Caramazza, 1991). For example, some investigators have found that visual processing of complex pictures presented at brief exposures is slowed down in these patients in comparison to normal subjects (Friedman & Alexander, 1984), and that visual processing of items presented in arrays is also impaired under limited visual exposure conditions (Farah & Wallace, 1991; Kinsbourne & Warrington, 1962; Levine & Calvanio, 1978; Rapp & Caramazza, 1991).

Evidence of impaired single letter processing, in at least some LBL readers, has been invoked as an account of this reading deficit (Arguin & Bub, 1994; Howard, 1990). Arguin and Bub (1994), in a series of elegant experiments, demonstrated: (1) that their patient showed letter recognition difficulties in the presence of preserved processing of structural representations, and (2) that this letter recognition disorder was due to a loss of "automatic" identification of familiar characters. However, as pointed out by the authors themselves, evidence demonstrating impaired letter processing in these patients does not rule out impairments at other levels of processing. Furthermore, it remains unclear why on this account LBL readers do not produce many more visual errors in reading (e.g. bear → pear; bear → beer).

Warrington and Shallice named the LBL reading deficit "word form dyslexia" to reflect their hypothesis that the damage responsible for the disorder is at the level of orthographic lexical forms. A consequence of this type of damage is to force patients to process words sublexically by naming the letters and accessing the lexicon through the intact spelling system[2]. Variants of Warrington and Shallice's interpretation of LBL as resulting from an impairment to the word form system have been adopted in modified form by others (Bowers, Arguin, & Bub, 1996a, Bowers, Bub, & Arguin, 1996b; Patterson & Kay, 1982). Patterson and Kay (1982) proposed a revised interpretation according to which damage occurs not to the word form system itself, but rather to the access procedures to this system. This induces a letter-by-letter parsing of the input string, with the consequence that whole-word recognition is not possible. These versions of the "word form dyslexia" interpretation of LBL reading have been challenged by the finding that some patients with LBL reading show word superiority effects (WSE) when lexical and nonlexical items are shown at exposures too brief for overt recognition and report (Bub et al., 1989;

[2] No explicit account has ever been provided of how this process is supposed to work.

Reuter-Lorenz & Brun, 1990; but see Kay & Hanley, 1991). To accommodate the latter results, Bowers et al. (1996a, 1996b) propose instead that LBL reading is the result of a disconnection between a normally functioning orthographic input lexicon and normally functioning semantic and phonological lexical components. However, all three "word form dyslexia" accounts of LBL reading encounter difficulties in explaining the finding that some LBL readers show (partial) semantic access (as evidenced by above-chance performance on categorisation tasks) of lexical items that were shown at exposures too short for overt reading and recognition (Coslett & Saffran, 1989; Coslett,Saffran, Greenbaum, & Schwartz, 1993; Shallice & Saffran, 1986).

An entirely different approach has been taken by Coslett and Saffran (1989). They proposed that the word superiority and categorisation effects in LBL readers arise not in the left-hemisphere word recognition system (which is supposedly either damaged or accessed in a letter-by-letter fashion) but in a functionally and anatomically independent lexical system located in the right hemisphere. On this interpretation, LBL reading can be used to investigate the processing structure of reading mechanisms in the right hemisphere. Coslett and Saffran argue that LBL readers' performance is best understood in the following way: Whenever explicit word identification is required, visual input is first analysed in the right hemisphere and information is transmitted in a serial, laborious fashion to the intact left-hemisphere word form system; however, when explicit identification is not required, then the visual input is processed by the right hemisphere word recognition system (which does not allow overt identification because of its lack of a phonological output system).

Although the various accounts of LBL reading briefly reviewed here are often discussed as alternative explanations of the disorder (e.g. Behrmann & Shallice, 1995), it is entirely possible that they each constitute plausible explanations for *different* forms of a heterogenous reading disorder which share only the superficial characteristic of LBL reading. It is important, therefore, to describe clearly the performance of such cases on the relevant dimensions along which supposedly alternative accounts can be compared. In this paper, we report the case of MJ, a 62-year-old woman, who suffered a left occipital infarct in 1989 resulting in a complete right homonymous hemianopia, and in laborious reading with characteristic features of LBL reading. Here, we attempt to (1) evaluate whether MJ's reading performance satisfies the criteria for being considered a LBL reader, (2) explore whether MJ's reading difficulty is related to her visual field cut, (3) explore whether her visual processing difficulty is limited to verbal materials, (4) investigate whether she demonstrates implicit reading in categorization tasks, and (5) explore whether this case can further our understanding of implicit reading processes. Her performance is compared to that of a hemianopic patient (JG) who does not show LBL reading and to that of a neurologically intact control subject (TG).

CASE HISTORIES

MJ, a right-handed woman, was 62 years old at the time of testing. She is a high-school graduate and currently a homemaker. Premorbidly she was an avid reader. MJ suffered a left occipital CVA on 27 June 1989, which left her with right-side weakness, a right visual field cut, and severe reading difficulties. Perimeter tests of her visual fields dated January 1995 reveal a complete right visual field cut with no macular sparing. A brain MRI dated 3 July 1989 shows a 1.5cm lesion in the left optic radiation near the thalamus along with multiple periventricular white matter lesions with involvement of the corpus callosum.

Language testing revealed normal processing in all tasks but reading. MJ's speech was fluent and normally formed, with no evidence of dysarthria. Word and sentence level processing were normal. MJ performed flawlessly on all comprehension (grammaticality judgement; picture-sentence/ word matching), naming (oral and written naming to picture and tactile confrontation), and repetition tasks. Written spelling, oral spelling, and aural recognition of orally spelled words were also accurate (98%, 95%, and 96% correct, respectively). Performance on visual tasks with unlimited exposure was flawless (drawing, copying with and without delay, line cancellation and bisection, search tasks) (see Fig. 1), as was letter naming at 100msec (upper and lower case) and 16msec exposures (upper case) (see Table 1). Colour naming and face recognition were normal.

Table 1. MJ's Letter Naming Performance in Free Vision and at 16msec Exposure

Exposure	*Case*	*%*	*No*
1sec	Upper	100	(26/ 26)
	Lower	100	(26/ 26)
16msec	Upper	96	(96/ 100)

Errors: Q > O; W > V; B > D; G > C.

Reading performance, although accurate (94% correct) and unaffected by lexical factors (concreteness, word category, regularity, and frequency) (see Table 2), was characterised by LBL naming prior to word reading. Sentence reading was virtually impossible. At limited

Table 2. MJ's accuracy (% Correct) in Reading Single Words at Unlimited and at 500msec Exposures

	Exposures	
Lexical Effects	*Unlimited*	*500msec*
Abstractness		
Abstract	100	40
Concrete	100	40
Grammatical class		
Nouns	86	57
Verbs	93	30
Adjectives	86	47
Functors	90	70
Spelling-to-sound regularity		
Regular consistent	100	50
Regular inconsistent	97	50
Exceptional	90	50
Frequency		
High frequency	96	60
Low frequency	91	34
Total	94	48

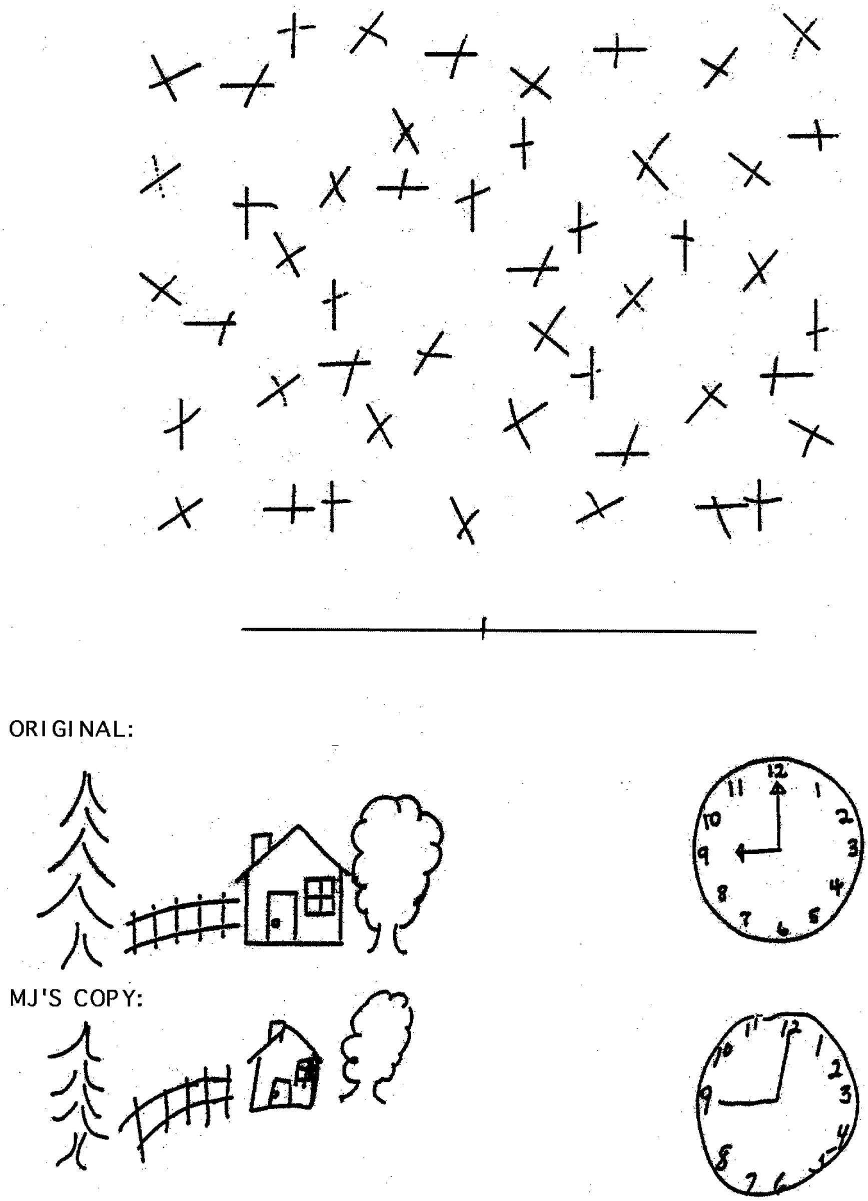

Fig. 1. MJ's line cancellation, line bisection, and copying performance.

Table 3. Error Percentage per Letter Position in Reading for MJ (500 msec Exposure) and JG (Free Vision)

			Letter Position					
	N	*Word Length*	*1*	*2*	*3*	*4*	*5*	*6*
MJ	51	4	8	9	31	96		
	20	5	5	25	45	95	110	
	38	6	3	15	45	79	92	103
JG	35	4	11	16	33	73		
	34	5	3	6	15	47	85	
	28	6	4	7	22	29	64	72

exposure (500msec), MJ's reading performance markedly deteriorated and a clear frequency effect emerged (see Table 2). Her reading errors were mainly lexical substitutions that tended to share the initial letters with the target word (e.g. belief → below). Error analysis revealed that the percentage of errors per letter position is a function of distance from the beginning of the word (see Table 3).

JG is a right-handed, 66-year-old woman, with 2 years of college. JG was also an avid reader premorbidly. She suffered a first left posterior occipital CVA on February 1994, and a second CVA in April, 1994, which involved the left temporal-occipital region. Brain MRI revealed a focal abnormality in the occipital area, with mild bilateral involvement. JG presents with a right visual field cut, and right-side weakness. She reports experiencing a right visual field cut on both the upper and lower quadrants, which was confirmed during evaluation. JG also complains of some memory loss as well as difficulties in calculation.

Performance on language screening tests revealed moderately decreased reading accuracy with visual/ morphological errors, a mild word finding difficulty in confrontation naming tests with semantic errors, and mildly impaired spelling and number processing abilities. Performance on visual tasks was normal except for delayed copying and for face recognition which were mildly impaired. Colour naming was flawless.

In free vision, JG's reading performance was impaired. Her reading errors, like MJ's, were mainly lexical substitutions that tended to share the initial letters with the target word. Error analysis revealed that, also like MJ, JG's percentage of errors per letter position tended to be a function of distance from the beginning of the word (see Table 3).

TG is a right-handed, 59-year-old woman with high-school education. She worked as a proofreader. TG participated in the study as a control subject. Her medical history is not significant for brain damage.

IS MJ A LETTER-BY-LETTER READER?

A set of tasks was used to investigate MJ's ability to process written language and rule out gross visual perceptual deficits. The tasks included reading in free vision and at different exposure durations, lexical decision tasks, aural recognition of spelling words, and oral and written spelling tasks. An object naming task was included to assess gross perceptual processing.

Reading in Free Vision

MJ was administered a reading task comprising 120 words ranging in length from 3 to 8 letters (20 words of each length), matched for frequency and concreteness. Words were presented one at a time, printed in 24-point capital letters, centred on a sheet of paper. The words were first presented displayed horizontally, and later, at regular intervals of 1 month, they were presented displayed vertically and spaced out horizontally. Each display type presented the words in a different random order. Different display types were used to rule out the possibility that increases in reading latencies for letters on the rightmost side of words were due to a mild form of visual neglect. Reading latencies were measured with a stop-watch from the time the word was presented to the time a lexical response was given. Only correct responses were included in the length effect analyses.

There was no effect of word length on MJ's reading accuracy (see Table 4a), and errors (10, 12, and 11 responses for the horizontal, spaced, and vertical presentations, respectively) were mainly lexical substitutions that shared the initial letters with the target word (e.g. symphony → sympathy). A two-way ANOVA was performed on correct response latencies. The results showed a main effect of display types [$F(2,289) = 4.8$, $P < .01$], and of length [$F(5,289) = 28.5$, $P < .0001$] but no significant interaction [$F(10,289) = 1.1$, $P < .4$]. This indi-

Table 4a. MJ's Reading Accuracy (% and No. Correct) for Topographically Different Word Displays at Unlimited Exposure

	Display type		
Word Length	*Horizontal*	*Spaced*	*Vertical*
3	89 (16/ 18)	90 (18/ 20)	100 (19/ 19)
4	95 (19/ 20)	100 (19/ 19)	81 (13/ 16)
5	95 (19/ 20)	85 (17/ 20)	90 (17/ 19)
6	100 (18/ 18)	95 (18/ 19)	90 (17/ 19)
7	88 (14/ 16)	78 (14/ 18)	90 (17/ 19)
8	80 (16/ 20)	90 (18/ 20)	90 (18/ 20)
Total	91 (102/ 112)	90 (104/ 116)	90 (101/ 112)

e.g. Errors: Prestige → precise; circuit → circle; symphony → sympathy; bit → bill.

cates that MJ's reading performance is affected by a word length effect that is independent of display type (see Table 4b).

Mean response latencies and standard deviations for the different displays are shown in Table 4b. The comparison among the three subjects for the horizontal condition is shown in Fig. 2. MJ's reading performance for horizontally displayed words was compared with that of JG and TG. An overall two-way analysis of variance indicates a main effect of subject [$F(2,304) = 11.9$, $P < .0001$], a main effect of length [$F(5,304) = 1.4$, $P < .0001$], and a significant interaction [$F(10,304) = 10.6$, $P < .0001$]. Individual, two-way ANOVAs showed the following: For MJ versus JG there was a significant effect of subject [$F(1,194) = 1.1$, $P < .0001$], a significant effect of length [$F(5,194) = 10.7$, $P < .0001$], and a significant interaction [$F(5,194) = 9.8$, $P < .0001$]; for MJ versus TG there was a significant effect of subject [$F(1,206) = 1.7$, $P < .0001$], a significant effect of length [$F(5,206) = 11.9$, $P < .0001$], and a significant interaction [$F(5,206) = 11.7$, $P < .0001$]; and for JG versus TG there was a main effect of subject [$F(1,208) = 2$, $P < .0001$], no effect of length [$F(5,208) = 2.1$, $P < .07$], and no significant interaction [$F(5,208) = 2.1$, $P < .08$]. To assess further the effects of word length on reading performance, a series of independent *t*-tests was carried out for each subject, comparing performance at each length with performance at every other length. The comparisons for MJ revealed significant differences for each comparison except for five-letter vs. six-letter [$t(35) = 0.7$, $P < .5$] and seven-letter vs. eight-letter lengths [$t(28) = 0.09$, $P < .1$]; for JG no significant differences were obtained at any length, except for the shortest length (three-letter words), which was significantly different from lengths five-letter [$t(34) = -2.4$, $P < .02$], six-letter [$t(32) = -3.1$, $P < .004$], seven-letter [$t(30) = -2.8$, $P < .01$], and eight-letter [$t(32) = -2.3$, $P < .03$]; and for TG, no significant difference was obtained for any comparison. The results indicate that MJ's performance is qualitatively different from that of JG and TG. In particular, MJ's performance for horizontally displayed words is characterised by a marked length effect, with stepwise increases in reading latencies of up to several seconds. JG's performance for horizontal displays, although slower overall than that of the normal control, is not characterised by such progressive increases in latencies with longer stimuli.

Table 4b. MJ's Mean Response Time (Sec) and SD for Topographically Different Word Displays at Unlimited Exposure

	Display type		
Word Length	*Horizontal*[a]	*Spaced*	*Vertical*
3	1.4 (0.8)	1.6 (0.8)	2.2 (1.1)
4	2.5 (1.1)	3.0 (1.8)	3.5 (2.7)
5	4.5 (3.7)	3.6 (1.8)	4.2 (2.4)
6	3.8 (1.9)	3.4 (1.8)	6.1 (4.3)
7	7.3 (4.9)	5.1 (2.4)	8.3 (3.8)
8	7.5 (4.4)	7.5 (4.2)	7.6 (4.4)

[a]No effect of imageability on accuracy or RT; frequency effect on RT but not on accuracy.

Lexical Decision

In order to rule out the possibility that output processing deficits may be contributing to MJ's

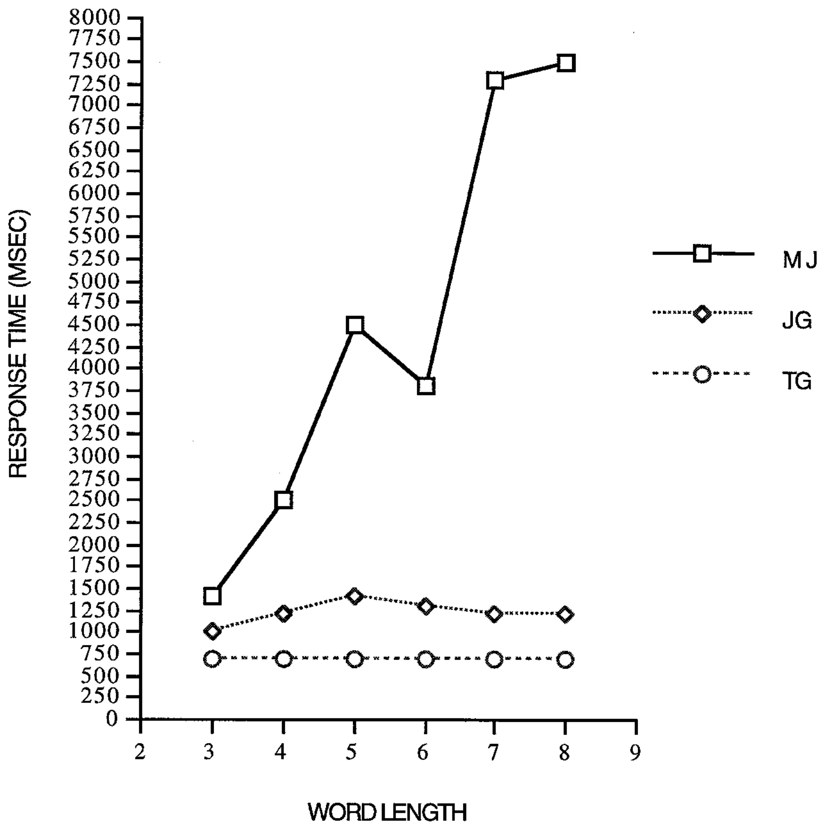

Fig. 2. MJ, JG, and TG—reading performance for horizontal displays.

reading difficulties, MJ was asked to perform a lexical decision task[3].

MJ was shown words and nonwords on a computer screen. Words were either four, six, or eight letters long and were matched for frequency. Nonwords were length-matched to the words and respected orthographic constraints of English orthography. There were 10 stimuli per experimental condition. Words and nonwords of different lengths were randomly intermixed. The following procedure was used: A fixation point would appear in the middle of the screen, followed by a 17msec screen refresh time and then by a target item printed in 24-point capital letters. The stimulus remained on the screen until a response was produced. Response times were measured

[3] As JG's lack of length effect in reading was considered sufficient evidence to conclude that she was not a LBL reader, and due to time limitations, JG was not administered the tasks in experiments 2 and 3.

from stimulus onset to response. MJ was instructed to look at the screen and press a computer key labelled "Y" for "yes" when she thought the stimulus was a word, and a key labelled "N" for "no" when she thought the stimulus was not a word. Stimuli were presented in two blocks. For the first block, the "Y" key was on MJ's left and the "N" key was on her right. For the second block, the locations of the "yes" and "no" keys were reversed. Only correct responses (Table 5) were included in the analysis of reaction times (Fig. 3).

MJ's overall accuracy was high (97% for both words and nonwords), but reaction times showed an effect of stimulus length [$F(2,32) = 7.8$, $P < .002$]: Longer items elicited longer reaction times, with abnormally steep increases. There was also a main effect of stimulus type, with words being recognised consistently faster than nonwords [$F(1,32) = 11.2$, $P < .004$]. There was no significant interaction between stimulus type and length [$F(2,32) = 0.5$, $P < .6$]. The presence of a main effect of stimulus length on reaction times in a task that only requires visual recognition, but no spoken output, indicates that MJ's abnormal reading latencies are most likely to be due to an input processing deficit and not to a deficit in accessing a phonological representation for spoken output.

Table 5. MJ's Lexical Decision Accuracy (% and No. Correct) for Words and Nonwords

	Stimuli	
Word Length	*Words*	*Nonwords*
4	100 (10/ 10)	90 (9/ 10)
5	90 (9/ 10)	100 (10/ 10)
6	100 (10/ 10)	100 (10/ 10)
Total	97 (29/ 30)	97 (29/ 30)

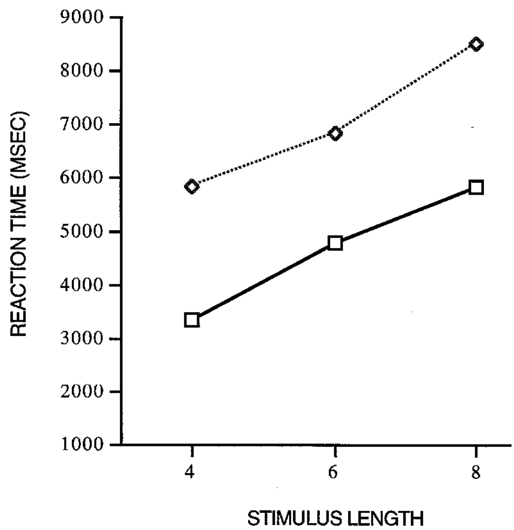

Fig. 3. MJ—lexical decision latencies.

Reading Accuracy at Different Exposure Durations

MJ was shown words of different lengths at different exposure durations. Three sets of words, matched for frequency and spelling-to-sound regularity, were used. Each set was presented at a different exposure duration– 400msec, 500msec, and unlimited exposure, respectively. Within each set, four-, six-, and eight-letter words were randomly intermixed. Stimuli were presented centred on a computer screen, but no attempt was made to control eye movements. Stimuli were shown in 24-point capital letters. MJ was asked to read the words aloud. Her performance is summarised in Table 6 and Fig. 4.

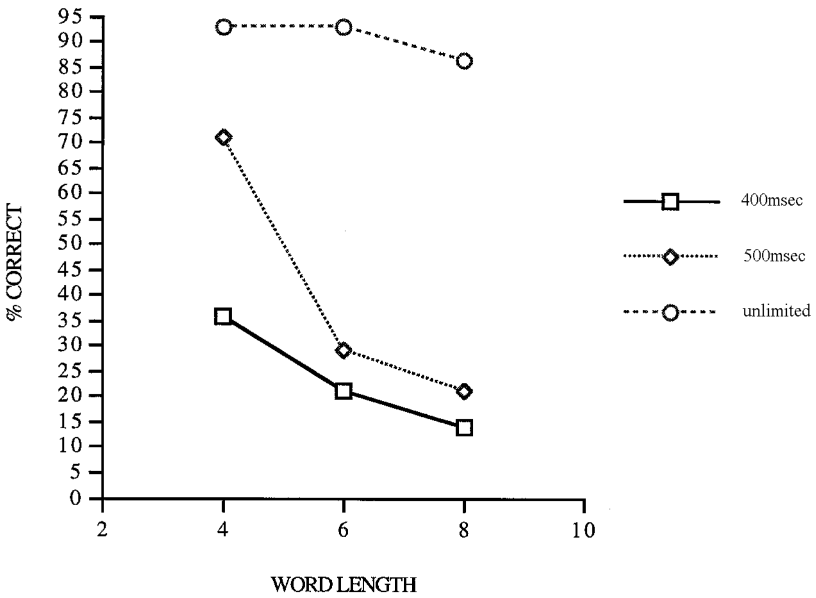

Fig. 4. MJ—The relationship between word length and reading accuracy at different exposure durations.

MJ's performance shows a marked effect of length [Friedman $\chi r^2(2) = 6, P < .05$]. Exposure duration greatly affected performance: Brief exposures resulted in very poor reading accuracy, with poorer performance for longer words. These results indicate that MJ's reading accuracy is sensitive to the manipulation of visual variables such as exposure duration. In particular, they indicate that at brief exposures MJ does not have time to scan the visual input letter by letter, and she is forced to "guess" on the basis of whatever partial letter information she can extract from the stimulus (usually parts of the beginning of the word).

Table 6. MJ's Reading Accuracy at Different Exposure Durations for Words of Different Length—% (No.) Correct

	Exposure		
Word Length	*400*	*500*	*Unlimited*
4	36 (5/ 14)	71 (10/ 14)	93 (13/ 14)
6	21 (3/ 14)	29 (4/ 14)	93 (13/ 14)
8	14 (2/ 14)	21 (3/ 14)	86 (12/ 14)
Total	24 (10/ 42)	41 (17/ 42)	91 (38/ 42)

Recognition of Spelled Words and Oral and Written Spelling Production

Results of the reading and lexical decision tasks clearly indicate that MJ has severe difficulties in recognising written words. A possible cause of these difficulties could be damage to her knowledge of the orthographic structure of words. To assess the integrity of this knowledge, MJ was administered the following three tasks: aural recognition of spelled words, oral spelling, and writing to dictation. The same list of words used in the reading test were used in these tasks. Words were presented in different random orders in each task, which were administered at 1-month intervals from the previous task. In the aural recognition task, the examiner spelled aloud a word and MJ was asked to identify it (e.g. "bee", "ay", "tee" for bat). In the oral and written spelling tasks, the examiner said a word aloud and MJ was required to spell it either orally or in writing. Her accuracy on these tasks is summarised in Table 7. MJ performed these tasks quickly and without difficulty. There was no effect of letter position on the very few errors produced in these tasks. These results indicate that MJ's difficulties in reading are not due to a general problem in processing orthographic representations. Furthermore, they indicate that her difficulties in processing orthographic representations occur prior to the point at which graphemic strings are used to access lexical orthographic forms. For if this were not the case, then MJ's performance on the aural recognition task would have been characterised by the same difficulties she encountered in reading.

Table 7. MJ's Aural Recognition and Spelling Accuracy (% and No. Correct)

	Task					
Word Length	*Aural Recognition*		*Oral Spelling*		*Writing to Dictation*	
3	100	(20/ 20)	100	(20/ 20)	100	(20/ 20)
4	95	(19/ 20)	100	(20/ 20)	95	(19/ 20)
5	90	(18/ 20)	90	(18/ 20)	90	(18/ 20)
6	100	(20/ 20)	95	(19/ 20)	90	(18/ 20)
7	95	(19/ 20)	95	(19/ 20)	90	(18/ 20)
8	95	(19/ 20)	85	(17/ 20)	95	(19/ 20)
Total	96	(115/ 120)	94	(113/ 120)	93	(111/ 120)

e.g. Errors: particle → practical; athlete → athlet; rhythm → rthym.

Object Naming

Object naming is an extremely complex task involving many cognitive and linguistic components. Poor performance on this task is hardly informative since there are many possible causes that could be responsible for the performance. However, good performance would suggest that the component processes, from visual recognition to speech articulation, must be grossly intact. Indeed, an argument that has been used against the claim that LBL reading is a perceptual problem is the finding that LBL readers do not show deficits in processing nonlinguistic stimuli, such as objects, pictures of objects, or complex scenes (Patterson & Kay, 1982; Warrington & Shallice, 1980; but see Friedman & Alexander, 1984). And, in fact, many of these patients do not report subjective difficulties in these tasks the way the do for reading. To see whether MJ was similarly unimpaired in processing visual objects, we asked her to perform a series of confrontation naming tasks using a subset of the Snodgrass and Vanderwart set of pictures. On different occasions she was asked to name pictures of objects presented in free vision, at 250msec exposure, and at 100msec exposure (see Table 8). Time-limited presentations were shown centred on a computer screen.

Table 8. Percentage (and No.) Correct Responses in Confrontation Naming at Different Exposure Durations

	MJ	*JG*	*TG*
Unlimited exposure	97 (126/ 130)	96 (250/ 260)	NA
250msec (centred)	92 (119/ 129)	NA	NA
100msec (centred)	84 (119/ 142)	91 (129/ 142)	100 (142/ 142)
Examples of errors			
Unlimited	fly → bee	fly → spider	
250msec	fork → spoon		
100msec	beetle → fly, or ant	needle → paintbrush	

In the unlimited exposure duration condition, MJ's performance was almost flawless and not different from JG's performance[4] [MJ vs. JG: $\chi^2(1) = .003$, $P < .9$, n.s]. At highly reduced exposures (100msec), MJ's performance decreased to 84% accuracy, which is significantly different from the performance of the hemianopic control [MJ vs. JG: $\chi^2(1) = 10$, $P < .01$] and the normal control [MJ vs. TG: $\chi^2(1) = 23$, $P < .001$]. Although such performance is indicative of a mild perceptual deficit, MJ's ability to identify pictures of objects remains rather accurate. Furthermore, her errors reflected difficulty in perceiving details of the pictures rather than gross confusion about the identity of the target items. For example, she mistook a beetle for a fly, a rabbit for a squirrel, and a flute for a pen. These findings indicate that MJ's processing of complex visual objects is only mildly affected and not significantly different from that of the hemianopic (and under certain conditions the normal) control.

Discussion

In this section we addressed the issue of whether MJ's performance is comparable to other LBL readers reported in the literature on basic reading and lexical access tasks. The major result is that MJ shows a marked word length effect in reading and recognising written words. In free vision tasks, she took on average 2 to 8 seconds to read three- and eight-letter words– abnormally long response times. Similar effects of length were obtained for stimuli presented in horizontal, vertical, and spaced horizontal displays. A similar length effect was observed in a lexical decision task: Consistently slower responses were obtained for words (3 to 6 seconds) and nonwords (6 to 9 seconds) ranging in length from four to eight letters. Reduced exposures of stimuli decreased reading accuracy, with longer words affected more than shorter ones (93% vs. 86% correct for four- vs. eight-letter words with unlimited exposure). Taken to-

[4] JG was administered a larger set of pictures as part of another study. All pictures shown to MJ were included in JG's set.

gether, these results indicate that MJ's reading difficulties are characterised by an abnormal increase in recognition latencies as words get longer, and increasing error rates for longer words at short exposure durations.

MJ's excellent performances in the recognition of orally spelled words, and in oral and written spelling production, indicates that MJ's reading difficulty is limited to the processing of orthographic strings from the visual modality and does not extend to output processes or to "orthographic" processing through the auditory modality. Furthermore, as reported in the Case Histories, MJ demonstrates essentially perfect performance in processing single letters, even when these are displayed at exposures as short as 16msec. And, as indicated by her performance in the visual object naming task, MJ does not have gross perceptual impairments. These results taken together allow the classification of MJ as a classic LBL reader– that is, she has intact lexical orthographic knowledge, she has intact knowledge of graphemes, she does not have gross perceptual impairments, but she has severe difficulties in the rapid recognition of written words.

Although MJ's and JG's reading performances show several similarities, such as a gradual increase in the percentage of errors for letter positions progressively further away from the beginning of the word, JG's reading performance lacks the typical length effect demonstrated by LBL readers. Thus, we can conclude that even though MJ and JG both present with a right visual field cut and a reading deficit characterised by increasing error rates for progressively rightmost letter positions, only MJ shows the characteristic length effect of a LBL reader. In other words, a visual field cut (found in both MJ and JG) is not a *sufficient* condition for being a LBL reader.

MJ's LETTER-BY-LETTER READING IS NOT A LANGUAGE SPECIFIC DEFICIT

This section of our investigation addresses the hypothesis that MJ's LBL reading results from a deficit at a prelexical perceptual stage. One argument that has been used against this hypothesis in the case of other LBL readers is that they do not demonstrate difficulties processing nonlinguistic materials such as pictures. In the previous section we showed that, under certain conditions, this is also the case for MJ. However, more stringent tests are needed before we can rule out the possibility that LBL reading is not the result of a perceptual deficit.

In the following series of tests we assess MJ's ability to process multiple items presented simultaneously in her visual field. Following Warrington and Shallice (1980), we first used a visual span task requiring subjects to detect and report two simultaneously displayed items. Then, following Rapp and Caramazza (1991), we used a letter detection and a line orientation detection task to assess MJ's ability to detect a target item among distracters presented at several spatial locations.

Visual Span

Among other arguments (see the General Discussion), the finding of preserved visual span in some LBL readers led Warrington and Shallice (1980); see also Warrington & Langdon, 1993) to conclude that LBL reading is not the result of a low-level visual processing deficit but rather an inability to process multiple items simultaneously at higher levels of lexical processing.

To assess MJ's and JG's visual span, we used a task originally used by Warrington and Shallice (1980, Experiment 1b). As described in that paper, two numbers were placed on either end of a four-, five-, six-, seven-, and eight-letter word (e.g. 4jury6). Stimuli were printed in lower-case letters, Geneva font size 20, and displayed using the software Psycholab v.1. Items were displayed for 150msec to prevent eye movements. Different word lengths were tested in a fixed order from short to long. There were 5 stimuli in each length condition for a total of 25 stimuli. Subjects were instructed to report the digits. There were two versions of the experiment: one in which stimuli were displayed centred and one in which stimuli were displayed left of fixation. Both versions were administered to MJ, JG, and TG. Results are shown in Table 9.

For the centred condition, both MJ and JG performed significantly more poorly than the normal control in reporting both digits correctly [MJ vs. TG: $\chi^2(1) = 23, P < .001$; JG vs. TG: $\chi^2(1) = 25,\ P < .001$]. When correct report for the left and the right side digit are considered independently, it can be seen that both MJ and JG reported the digit on the left of the word significantly more often than the digit on the right [MJ_L vs. MJ_R: $\chi^2(1) = 23, P < .001$; JG_L vs. JG_R: $\chi^2(1) = 22,\ P < .001$]. Distance from fixation point (i.e. intervening word length) did not have any effect on performance for any of the subjects, but this may be an artefact due to the small sample size.

For the left of fixation condition, MJ still had difficulty reporting both digits relative to the normal control [TG vs. MJ $\chi^2(1) = 20, P < .001$]

Table 9. MJ's, JG's, and TG's Performance on the Visual Span Task (% and No. Correct). For Each Display Type (Centred and Left of Fixation), Results Are First Reported for Both Digits, and Then for the Left and the Right Digit Independently

	MJ[a]	*JG*[a]	*TG*[a]
Centred stimuli			
Both digits correct	8 (2/ 25)	0 (0/ 25)	100 (25/ 25)
Left digit	100 (25/ 25)	88 (22/ 25)	100 (25/ 25)
Right digit	8 (2/ 25)	0 (0/ 25)	100 (25/ 25)
Left of fixation			
Both digits correct	20 (5/ 25)	63 (15/ 25)	100 (25/ 25)
Left digit	88 (24/ 25)	96 (24/ 25)	100 (25/ 25)
Right digit	20 (5/ 25)	64 (16/ 25)	100 (25/ 25)

[a]No effect of word length; chance level = 10%.

and so did JG [TG vs. JG: $\chi^2(1) = 10$, $P < .01$]. However, when correct report is considered separately for the left-side and the right-side digit, it can be seen that MJ's performance for the right digit improves very little relative to her performance in the centred condition [MJ_{RC} vs. MJ_{RL}: $\chi^2(1) = 3$, $P < .1$, n.s.] whereas JG's performance improves considerably [JG_{RC} vs. JG_{RL}: $\chi^2(1) = 16$, $P < .001$]. Importantly, distance from the fixation point (i.e. intervening word length) did not have an effect on performance for either subject but, once again, this result must be interpreted cautiously because of the small number of observations.

These results indicate that unlike Warrington and Shallice's (1980) patient RAV, MJ shows a severely reduced visual span even when stimuli are presented in the intact left visual field. The results also show that MJ's reduced span is not simply due to her field cut since she performed considerably worse than the hemianopic control. Thus, MJ's right homonymous hemianopsia cannot entirely account for her LBL reading.

Letter Detection

Following Rapp and Caramazza, (1991, Experiment 3), we used a letter search task to evaluate whether MJ's and JG's ability to detect a target letter among distractors was affected by (1) the absolute spatial location of the target (i.e. whether a target item is presented left, right, or at fixation), and (2) the relative spatial location of the target (i.e. whether a target item is presented in the first, middle, or final position in a string of items). Five- and three-letter strings were presented. There were three versions of the experiment, defined by the position of the letter strings relative to fixation. In one version, the five-letter strings appeared centred across fixation; in another version, the stimuli were displayed with the last letter at the point of fixation (left of fixation condition); and, in another version, the first letter was shown at fixation (right of fixation condition). In the three-letter string conditions, stimuli were presented across the five positions defined by the five-letter string (see Table 10 and Figure 5). Thus, they could either be centred across the five-letter strings' midpoint or aligned with its left or right margin. This allows us (1) to examine performance at different absolute locations relative to fixation (+ 4, + 3, + 2, + 1, F, –1, –2, –3, –4) while maintaining relative positions constant, and (2) to determine whether performance at any of these positions is affected by the relative position of an item within a string. Thus, for example, with three-letter strings we could examine whether performance at location + 2 differs according to whether the item at that location is the rightmost or leftmost in a string.

The letters K, X, Z, N, and Y were used as target items. The distracters were D, J, G, R, B, and P. There were a total of 280 trials in each version of the experiment. A target was present among distracters on half of the trials (total $N = 140$). Half of the stimuli contained five letters and half three letters, randomly intermixed. The maximum eccentricity of a stimulus was approximately 2.5°. Stimuli were displayed on a black-and-white computer screen using the software Psycholab v.1.

Letters were all capitals, Geneva font size 24, and appeared in black on a white background. All three versions were presented to MJ in a randomised order (total $N = 840$ trials); only the centred version was presented to JG and TG (total $N = 240$ trials).

On each trial a target letter appeared at fixation for 150msec, followed by an ISI of 50msec, and then a string of either three or five letters, which remained on the screen for 150msec (see Table 10 and Fig. 5). Subjects were instructed to keep their eyes at fixation and to press a computer key each time they detected the target item in the letter string.

The results for all three subjects are shown in Table 10. A first comparison was carried out between MJ's overall performance on the centred condition and JG's and TG's performance on the same condition separately for the five- and three-letter string conditions. MJ performed worse than the normal control both in the five-letter [MJ_5 vs. TG_5: $\chi^2(1) = 23.04$, $P < .001$] and the three-letter strings conditions [MJ_3 vs. TG_3: $\chi^2(1) = 34.8$, $P < .001$], but she did not perform worse than the hemianopic control in either the five-letter [MJ_5 vs. JG_5: $\chi^2(1) = 1.96$, $P < .2$] or the three-letter string condition [MJ_3 vs. JG_5: $\chi^2(1) = 0.64$, $P < .5$].

A second set of analyses was performed to compare MJ's performance on absolute positions at centre, left of fixation, and right of fixation, and on relative initial, middle, and final string positions for three-letter strings. Two-way ANOVAs for three-letter strings

Table 10. Letter Detection Task—% Correct per Display Position

	MJ					*JG*					*TG*				
Display type	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Left:					F										
5-letter string	60	30	10	50	60										
3-letter string	100	100	50												
		90	100	80											
			100	100	70										
Centre:			F					F					F		
5-letter string	90	90	70	0	0	100	100	80	20	20	90	100	100	100	100
3-letter string	100	80	50			100	100	80			100	100	100		
		90	90	10			100	100	0			100	100	100	
			90	20	0			100	20	0			100	100	100
Right:	F														
5-letter string	80	10	0	0	0										
3-letter string	90	0	0												
		60	0	0											
			10	0	0										

$N = 10$ per cell; chance level = 10%

Example of Events:		Exposure Duration:
time 0	READY?	
time 1		
time 2	X	150msec
time 3		50msec
time 4	B D X	150msec
response	"yes" if there is a match	
time 6	READY?	

Example of display positions (on each trial either a five- or three-letter single string would appear preceded by a target item):

Condition:					Fixation Point				
Centred					+				
5-letter strings			1	2	3	4	5		
3-letter string			1	2	3				
				1	2	3			
					1	2	3		
Left of fixation					+				
5-letter strings	1	2	3	4	5				
3-letter strings	1	2	3						
		1	2	3					
			1	2	3				
Right of fixation					+				
5-letter strings					1	2	3	4	5
3-letter strings					1	2	3		
						1	2	3	
							1	2	3

Fig. 5. Design of Letter Detection Task.

indicate the presence of a main effect of display type [$F(2,18) = 24.65$, $P < .0001$], a main effect of relative string position [$F(2,18) = 13.58$, $P < .0003$], but no interaction [$F(4,18) = 1.99$, $P < 1$, n.s.]. These results indicate that MJ's performance is affected by both absolute (left of vs. right of fixation) and relative (first vs. last letter in a string) position of the items in visual space.

The finding of an effect of absolute letter position is not surprising given MJ's visual field cut. However, there is also an effect of relative position with accuracy systematically lowest at the rightmost position in each three-letter stimulus. This effect occurs for strings of letters presented entirely within the intact left visual field. This can be seen best by comparing performance at the relative position 3 of stimuli presented leftmost in the left display (50%) with performance at the relative position 1 of stimuli presented rightmost in the left display (100%). These results are consistent with those obtained in the visual span task, where it was found that MJ could report the left digit correctly but made many errors for the right digit.

Line Orientation Detection

In order to investigate whether MJ's spatially determined deficit extends to the processing of nonlinguistic stimuli, she was tested on an orientation detection search task identical in design to the letter search task discussed earlier. The task was designed to evaluate whether MJ's ability to detect a target item among distracters was affected by the absolute and/or relative spatial location of the target. Five- and three-item strings were presented.

Horizontal (—), vertical (|), and tilted to the right (/) lines were used as target items. The same items were used as distracters, but on each trial target items never occurred twice (e.g. target: "—"; five-item string " | / — | / "). There were a total of 168 trials in each version of the experiment. A target was present among distracters on half of the trials (total $N = 84$). Half of the stimuli contained five lines and half three lines, randomly intermixed. The maximum eccentricity was approximately 2.5°.

Stimuli were displayed on a black-and-white computer screen using the software Psycholab v.1. Lines were displayed in bold, size 24, and appeared in black on a white background. All three versions of the experiment were given to all subjects, with stimuli within and across conditions appearing in a randomised order (total $N = 504$ trials).

On each trial a target line appeared at fixation for 150msec, followed by an ISI of 50msec, and then a string of either 3 or 5 lines, which remained on the screen for 150msec. Subjects were instructed to keep their eyes at fixation and to press a computer key each time they detected the target item in the string (see Fig. 5).

MJ's and JG's performance is shown in Table 11a, and TG's performance is shown in Table 11b. MJ's overall performance, collapsing across left, centred, and right conditions was compared to JG's and TG's overall performance on the same conditions. MJ performed less accurately than the normal control for both five- [MJ_5 vs. TG_5: $\chi^2(1) = 21.16$, $P < .001$] and three-item strings [MJ_3 vs. TG_3: $\chi^2(1) = 16.81$, $P < .001$], but did not differ from the hemianopic control for either five- [MJ_5 vs. JG_5: $\chi^2(1) = 0.09$, $P < .8$] or three-item strings [MJ_3 vs. JG_3: $\chi^2(1) = 2.01$, $P < .95$].

A second analysis was performed to compare MJ's performance on absolute positions (left vs. right of fixation), and on relative initial, middle, and final string positions for three-item strings. A two-way ANOVA indicated the presence of a main effect of fixation [$F(1,12) = 19$, $P < .00$], a main effect of relative string position [$F(2,12) = 5.9$, $P < .02$], but no interaction [$F(2,12) = .9$, $P < .4$]. These results replicate the previous findings in the letter detection task, and indicate that MJ's performance for nonlinguistic items is affected by both absolute (left vs. right of fixation) and relative (first vs. last item in a string) position of the items in visual space.

The same type of analysis for JG's results revealed a main effect of fixation [$F(1,12) = 64$, $P < .001$], but no effect of relative string position [$F(2,12) = 2.7$, $P < .1$, n.s.], nor of interaction [$F(2,12) = 1.6$, $P < .24$, n.s.].

Discussion

Taken together, the findings reported in this section indicate that (1) MJ presents with a deficit that is not entirely accounted for by her right visual field cut, as errors occur also for items displayed entirely within the good visual field; (2) this deficit affects performance for linguistic and nonlinguistic items alike; and (3) performance is characterised by increasing difficulty in processing progressively more right parts of the stimuli.

These results are consistent with previous reports (e.g. Kay & Hanley, 1991; Montant, Nazir, & Poncet, this issue), which indicate that processing of arrays of items (linguistic and nonlinguistic) is deficient in some LBL patients, and that this may be the source of the observed LBL reading performance.

The results obtained thus far also indicate that MJ's deficit is dissimilar from other cases of LBL readers in various respects. As already noted, MJ's deficit involves a reduction of vis-

Table 11a. Orientation Detection Task: MJ's and JG's Performance (% Correct) per Display Position

	MJ					*JG*				
Display Type	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Left:					F					F
5-item	83	83	33	33	50	67	100	83	100	100
3-item	83	83	67			100	100	100		
		100	83	67			100	100	83	
			75	67	42			100	83	100
Centre:			F					F		
5-item	83	83	83	50	17	83	100	83	0	0
3-item	83	67	42			100	83	100		
	100	100	56				100	83	0	
			83	58	8			100	33	0
Right:	F					F				
5-item	100	67	17	0	0	100	17	0	0	0
3-item	83	58	8			100	0	0		
		83	17	0			33	0	0	
			17	0	0			0	0	0

N = 6 per cell; chance = 17%.

ual span, a finding that contrasts with other reports in the literature (e.g. case RAV of Warrington & Shallice, 1980). Also, MJ shows normal, rapid processing of single letters in contrast with numerous reports in the literature (Arguin & Bub, 1994; Bub & Arguin, 1995; Rapp & Caramazza, 1991). However, MJ's performance is also similar to that of other patients reported in the literature. For example, she shows mild difficulties in the processing of pictures of objects (Friedman & Alexander, 1984), and presents with a right homonymous hemianopsia. Some of the comparisons may not be appropriate, however. For example, case RAV (Warrington & Shallice, 1980) does not present with several characteristics that are commonly found in other LBL readers, and other LBL readers reported in the literature have not typically been tested for visual span.

Table 11b. Orientation Detection Task: TG's Performance (% Correct) Per Display Position

	Relative Bar Position				
	1	*2*	*3*	*4*	*5*
All displays[a]					
5-item	100	100	89	100	100
3-item	100	100	100		
		100	100	100	
			89	100	100

N = 18 per cell.

[a]Left, centre, and right displays collapsed; *No effect on RT.

Thus, we do not know whether a reduced visual span is or is not commonly associated with LBL reading. Nonetheless, the fact that visual span is not necessarily associated with the LBL reading disorder indicates that there may be different causes for this complex disorder. Similarly, since single-letter processing difficulties are not necessarily associated with the LBL reading disorder we may infer that different forms of perceptual deficits may contribute to the disorder.

The results presented thus far have served to demonstrate that MJ presents with the characteristic performance observed in LBL readers, and that, unlike some other cases, her deficit does not affect letter processing but is characterised by a reduction of visual span. Given these input processing characteristics, how might visual word recognition occur? Are the input conditions adequate for lexical access in the absence of explicit identification of words, as has been reported for other LBL readers (Buxbaum & Coslett, 1997; Coslett & Saffran, 1989; Coslett & Saffran, 1994a, 1994b). We address these questions in the following section.

DOES MJ SHOW IMPLICIT READING?

In order to address the question of whether lexical access can be achieved even when altered input processing may not be sufficient for recognition, we first tried to replicate previous findings reported in the literature (Coslett & Saffran, 1989; Coslett et al., 1993; Shallice & Saffran, 1986; Warrington, 1975; Warrington & McCarthy, 1983). It has been shown that some dyslexic patients' performance in categorisation tasks can be significantly above chance level even when items are presented at exposures too brief for overt reading and recognition. For example, Warrington and Shallice (1979) report the case of AR who, in a forced-choice task, could decide the semantic category of a word despite an inability to read it. We first tried to replicate this effect in a recognition task, and then we manipulated chance-level performance and visual similarity features between target and response in a word–picture matching task to see how these factors affect categorisation performance.

Semantic Categorisation

Following previous investigations of patients with alexia (Rapp & Caramazza, 1989; Warrington & Shallice, 1979) MJ was given a word categorisation task. In this task she was asked to read words individually displayed on a computer screen, and for those words that she failed to read she was asked to make a forced-choice decision about the semantic category to which the word belonged.

MJ was presented with a list of 161 words. The words were divided into 3 lists consisting of 54, 59, and 48 words, respectively. Within each list there were words belonging to three different categories (matched for frequency, letter length, and syllable length), such that the same three category names were presented for each categorisation judgement. For example, list 1 consisted of names of places, means of transportation, and household items.

Words were displayed centred for 200msec[5]– well below MJ's threshold for accurate recognition– and she was instructed to read aloud each word, guessing if unsure. If she read a word correctly, the trial was discarded, as were cases in which she produced an incorrect response. For cases in which she produced a "don't know" response (even after encouragement to guess), she was asked to choose from among three aurally presented categories the one to which she thought the word might belong. For example, if in list 1 MJ was presented with the word "truck", and if she was unable to give a lexical response, she was asked whether the word was a place, a means of transportation, or a household item.

The results are reported in Table 12, and show that 42% (67/ 161) of the words were read correctly, 23% (37/ 161) were read incorrectly, and 35% (57/ 161) elicited a "don't know" response. Categorisation performance with the 57 "don't know" items indicates a 60% accuracy level (34/ 57), which is significantly above chance [$\chi^2(1) = 7.29$, $P < .01$]. These results "replicate" the finding that LBL readers may be able to access the meaning of words they are unable to pronounce.

Table 12. Categorisation Task—% of Responses per Category

	Reading			
	Correct	*Incorrect*	*"Don't knows"*	*"Don't knows" Correct Categorised*
List 1				
Places	68	11	21	100*
Transport	53	13	34	100*
Household	35	20	45	60
List 2				
Animals	45	20	35	43
Foods	79	11	10	100*
Body parts	5	50	45	33
List 3				
Clothing	36	14	50	43
Names	26	26	48	60*
Professions	27	40	33	40
Total	42	23	35	60*

Exposure: 200msec; presentation: centred; categorisation chance = 33%.
*Significant $P < .01$.

Word–Picture Matching

It has been argued that patients' above-chance performance on categorisation tasks, like the one just described, may reflect direct access to superordinate semantic information despite failure to access the word's specific meaning (Warrington & Shallice, 1979). Findings of this sort have also been used to support the hypothesis of a right-hemisphere lexical/ semantic system that in such patients is disconnected from the left-hemisphere output lexical/ phonological system (see General Discussion). That is, MJ's performance in the

[5] In this and in the following experiments, exposure duration was set at the fastest speed that MJ could tolerate. When exposures below 200msec were attempted she reported that she could not see anything but a flash on the screen, and when encouraged to guess what the word might have been she stated that she was unable to do so.

categorisation task may be interpreted as indicating access to the right-hemisphere semantic system. For example, when presented with the word "TRAIN" she would be able to access the information that this is a "means of transportation" even though she would be unable to identify the specific sequence of letters (or sounds) that distinguish, say, "TRAIN" from "TRAM" or "TRAY". On this interpretation, items sharing a superordinate (i.e. semantic class) would be indistinguishable in terms of meaning (i.e. MJ would not be able to distinguish between "TRAIN" and "TRAM", but would be able to distinguish between "TRAIN" and "TRAY"). Thus, this hypothesis predicts that items belonging to the same category ("TRAIN" and "TRAM") should be confused more often than items belonging to different categories ("TRAIN" and "TRAY"), since in the latter case knowledge of their category membership should be sufficient to allow the distinction.

To test this prediction a word–picture matching task was designed in which two variables were manipulated– the degree of semantic and orthographic similarity between each word and the name of the picture presented for matching (Rapp & Caramazza, 1989). In this task, MJ was first presented with words displayed for 200msec and was asked to read them aloud. To ensure maximum processing of the visual input, items were displayed left of fixation. As before, items that she read either correctly or incorrectly were discarded. If she produced a "don't know" response, she was then presented with a picture and asked to decide whether the word and the picture matched. On 30% (*N* = 170) of the trials the word and the picture constituted a match (e.g. the word "TOOTH" and the picture of a tooth). The other 70% (*N* = 395) of the trials consisted of 6 categories, defined by different kinds of relationship between the word and the picture. Word and picture were either semantically similar (SS) (i.e. belonged to the same superordinate category– e.g., the word "SOCK" and the picture <glove>[6] from the category clothing) or semantically dissimilar (SD) (e.g. PLANE– <mouth>); and they were either visually similar (VS) (e.g. TAXI– <tank>) or visually dissimilar (e.g. PILOT– <dentist>). Two levels of visual similarity were used: for level A (low similarity), the words in the pair shared at least the first letter and had approximately the same length (e.g. PEAR– <plum>); for level B (high similarity), the word and picture name shared the first letter, they were of approximately the same length, and they shared at least 50% of the letters (e.g. TOE– <tie>). Visual dissimilarity (VD) is defined by the absence of a shared initial letter, and by fewer than 50% letters in common (e.g. MOUTH– <suit>). Based on these criteria, the following six categories were defined: (1) VD, SS: word and picture are visually dissimilar but semantically similar (e.g. SOCK– <glove>); (2) VD, SD: word and picture are visually and semantically dissimilar (e.g. PIE– <bow>); (3) VSA, SS: word and picture are visually similar at level A and share a

[6] With the symbolic representation < . . . > we mean the picture of the designated item.

superordinate category (e.g. PEAR– <plum>); (4) VSA, SD: word and picture are visually similar at level A but do not share a superordinate category (e.g. DOMINO– <donkey>); (5) VSB, SS: word and picture are visually similar at level B and share a superordinate category (e.g. TAXI– <tank>); (6) VSB, SD: word and picture are visually similar at level B but do not share a superordinate category (e.g. TOE– <tie>). Word lists for each of the conditions were approximately matched for average frequency. Test items were presented in five blocks, which were administered in successive testing sessions, with at least one non-testing day between each session.

MJ's performance on this task is summarised in Table 13, which indicates that 49% (276/ 561) of the words were read correctly, 16% (88/ 561) were read incorrectly, and 35% (197/ 561) elicited a "don't know" response. There were four missed responses (when MJ got distracted while the word was flashed on the screen). Matching performance with the 197 "don't know" trials led to 84.2% (48/ 57) correct "yes" responses, and 74.3% (104/ 140) correct "no" responses. This performance is significantly different from chance level [$\chi^2(1) = 57.1$, $P < .001$]. In particular, she accepts correct matches (e.g. TOOTH– <tooth>) at a rate significantly *above* chance [$\chi^2(1) = 367$, $P < .001$] and rejects incorrect matches at a rate significantly *above* chance [$\chi^2(1) = 67$, $P < .001$]. More importantly though, when matching performance for the "no" responses is analysed in terms of the semantic similarity factor, MJ's performance appears *not* to be affected by the semantic similarity between word and picture. Thus, she is just as likely to reject the

Table 13. Word picture matching task

		Reading Response (%)			Categorisation Response (%)	
Pair Type	Example	Correct	Incorrect	DK	Yes	No
Match	tooth–tooth	52	15	33	84	16
VD,SS	jaguar–tiger	57	17	26	0	100
VD,SD	plane–mouth	52	15	33	0	100
VSA[a],SS	butter–bun	47	17	36	8	92
VSA,SD	glove–ghost	35	12	53	22	78
VSB[b]–SS	taxi–tank	49	16	35	69	31
VSB,SD	pipe–pine	49	17	34	65	35
Total		49	16	35	77	23

VD = Visually Different; VS = Visual Similar; SD = Semantically Different; SS = Semantically Similar.

[a]Type A indicates low visual similarity.

[b]Type B indicates high visual similarity.

Exposure: 200msec; presentation: left of fixation; chance level: 50%.

picture of a tiger as a match for the word "JAGUAR" as she is to reject the picture of a ghost as a match for the word "GLOVE" [SS vs. SD: $\chi^2(1) = 1.4$, $P < .5$, n.s.]. When matching performance for the "no" responses is analysed in terms of the visual similarity factor, MJ's performance appears *not* to be affected by the visual similarity between word and picture when these share only the first letter and have approximately the same number of letters and syllables (e.g. PEAR– <plum>) [VD vs. VSA: $\chi^2(1) = 1.8$, $P < .2$, n.s.], but is affected by the visual similarity between word and picture when these share at least 50% of the letters (e.g. TAXI– <tank>) [VD vs. VSB: $\chi^2(1) = 6.5$, $P < .02$]. In particular, her matching performance is significantly *below* chance for items in the Visually Similar at level B condition [VSB,SS: $\chi^2 = 12.25$, $P < .001$; VSB,SD: $\chi^2 = 9.61$, $P < .01$].

These results indicate that MJ can correctly match words that she is unable to identify only when the available visual information facilitates sophisticated guessing ("yes" on matches (TOOTH– <tooth>), and "no" on items that are visually dissimilar (JAGUAR– <tiger>). However, when the visual information provided by the initial part of the word and by the picture does not help discriminate between correct and incorrect matches, MJ's performance clearly deteriorates, to the extent that she systematically accepts as a match incorrect items that are visually highly similar to the target (TAXI– <tank>).

Identity Priming

To further explore the possibility that implicit reading may occur in a patient like MJ, we used a semantic (identity) priming paradigm. In one version of the experiment, we asked MJ and TG[7] to categorise pictures of either animals or artefacts presented at fixation[8]. On half of the trials ($N = 288$), MJ was asked to press a key with her right hand each time she thought a target item represented an artefact (e.g. desk) and a key with her left hand each time she thought a target item represented an animal (e.g. rabbit). On the other half of the trials ($N = 288$), MJ had to perform the same task, but this time responded to animals with her right hand and to artefacts with her left hand. This was done to ensure that there was no contribution of handedness in her overall pattern of responses. On each trial, target items were preceded either by a pattern mask (pattern condition: ####–desk), or by a picture of an item belonging to the same category (i.e. an artefact for artefacts, and an animal for animals) but different from the target (unrepeated condition: frying pan–desk), or by the picture of an item belonging to the other category (i.e. animal for artefacts, and artefact for animals)

[7] We could not administer this task to JG as she had a mild semantic deficit (see Case Histories) that may have interfered with the priming process in uncontrollable ways.

[8] Pictures were selected according to whether they could be matched with words that fall in the medium frequency range and whether they could occupy a prespecified visual space on the screen (e.g. a picture of a piano may roughly occupy a squared area, but the picture of a flute would not).

(mixed condition: rabbit–desk), or by itself (repeated condition: desk–desk). There were 36 items for each possible combination for each hand, for a total of 576 trials. For example, there were 36 pairs of the type "####–desk" for the left hand and another 36 pairs of the same type for the right hand. MJ was asked to fixate a point which appeared at the centre of the screen for 1000msec, followed by an ISI of 500msec, a prime picture for 200msec, an ISI of 200msec, and finally a target item for 200msec. The exposure duration of primes and targets for TG were 16msec each. Reaction times were measured and responses that fell more than 2.5 S.D. above or below MJ's and TG's overall average reaction times, respectively, were excluded from further analyses. Responses given with the incorrect hand were also discarded. Overall, 20 responses were eliminated for MJ and 8 for TG. MJ's and TG's performance for the different categories is reported in Table 14.

Reaction times for the four experimental priming conditions were analysed after collapsing across hand and target category (animal and artefact). The results indicate that both MJ and TG showed a significant effect of identity priming relative to the pattern condition (MJ: $t = 3.55$, $P < .001$; TG: $t = 2.6$, $P < .01$), the unrepeated condition [condition (MJ: $t = 2.55$, $P < .01$; TG: $t = -3.51$, $P < .001$)], and the mixed condition [condition (MJ: $t = -2.51$, $P < .01$; TG: $t = -3.23$, $P < .002$)]. That is, previous exposure facilitates recognition of a target item and enhances categorisation responses. There was no significant difference among the other conditions for either subject.

A second version of the experiment was designed, which was identical to the first one except that words were used as primes instead of pictures[9], and both prime and target were displayed left of fixation. TG was given a shorter version of the experiment, with 58 items per category for a total of 232 trials. In

Table 14. Repetition Priming Task—Mean Reaction Times for MJ and TG

			Picture/picture		*Word/picture*	
Condition	*Prime*	*Target*	*MJ*	*TG*	*MJ*	*TG*
Singleton	"Pattern"	Desk	1060	549	966	544
Repeated	Desk	Desk	840	485	920	518
Unrepeated	Pot	Desk	975	560	924	541
Mixed category	Bear	Desk	965	542	891	552

*Significantly faster than the other conditions ($P < .01$).
**Significantly faster than the other conditions ($P < .03$).

[9] Words across the four different categories fell approximately within the medium frequency range and were approximately matched for length in number of letters, with words ranging from three to six letters in length. Words of different lengths were equally distributed across the four experimental conditions.

this version of the experiment, 23 responses were eliminated for MJ and 6 responses for TG. MJ's and TG's performance for the different categories is reported in Table 14.

As in the picture version of the experiment, responses were analysed after collapsing across hand and target category (animal and artefact). The results indicate that TG again shows a significant effect of identity priming relative to the pattern condition ($t = 2.2$, $P < .03$), the unrepeated condition ($t = 2.35$, $P < .02$), and the mixed condition ($t = 2.75$, $P < .007$). MJ did not show any facilitatory effects.

These results indicate that in spite of the fact that MJ demonstrates identity priming effects for pairs of repeated pictures, she shows no facilitation in her recognition of a picture with previous exposure to the name of the picture. Thus, there is no evidence that lexical and semantic activation have occurred in MJ's lexical system upon exposure to the prime word. In other words, we find no evidence of implicit reading in MJ.

Discussion

In this section we addressed the issue of whether implicit reading occurs in MJ. Using a categorisation task, we first replicated findings reported in the literature which indicate that "implicit reading" occurs for words that cannot be identified overtly. That is, MJ showed above-chance performance in categorisation of words that she failed to read. However, we then went on to show that the above-chance performance displayed by MJ is best accounted for in terms of sophisticated guessing. This conclusion is supported by findings obtained in a word–picture matching task, where MJ was asked either to accept or reject a picture as an appropriate match to a word that she had failed to read. In this experiment, we manipulated the degree of visual similarity between the input word and the name of the pictorial foil. The results indicate that at sufficient levels of visual similarity. MJ's performance deteriorates significantly below chance level as she systematically accepts the foils as correct matches. That is, when the information that she obtains from the initial part of the word is not sufficient to discriminate between a correct match and a foil, she appears not to have any further information available to help her constrain her responses. In other words, MJ does not appear to have access to lexical information for those word stimuli she has difficulty processing at short exposure durations. This is true for stimuli displayed entirely in the intact visual field. On this interpretation, MJ has access to words only after a laborious LBL analysis of the input stimulus, and her ability to categorise words she is unable to read is due to sophisticated guessing. That is, MJ's ability to extract *some* visual information from briefly presented words allows her to generate potential lexical candidates for response which, when paired with knowledge that the response is a member of a small set of categories, may be used to direct her choice to the correct category or item.

It has been claimed that implicit reading may only be expected under conditions in which the patient is discouraged from using an LBL reading strategy and is encouraged instead to use a "whole-word" recognition approach (Coslett & Saffran, 1994a, 1994b). Thus, it could be argued that MJ's performance in the categorisation and the word–picture matching tasks in which she was first asked to read the word may have reduced the likelihood of her using a whole-word reading strategy. However, this objection does not apply to the "identity" priming experiment. In this experiment, MJ was not required to read the priming words, but simply to perform a categorisation (animal vs. artefact) of the target picture. Both MJ and the normal control, TG, showed facilitatory effects of identity priming between pictures. However, unlike TG, MJ does not show such facilitation between a target picture and a prime word, even when both are displayed left of fixation. These results indicate that only visual iconic stimuli can be processed accurately and quickly in the right hemisphere and lexical stimuli cannot. In short, the results we have reported fail to demonstrate "implicit reading" in MJ and support the conclusion that (at least in her case) the priming effects observed in the categorisation and word–picture matching tasks merely reflect sophisticated guessing.

GENERAL DISCUSSION AND CONCLUSIONS

We have reported the case of MJ, who suffered a CVA that involved the left optic radiation near the thalamus and the corpus callosum, and that resulted in a complete right homonymous hemianopsia and a reading deficit characterised by a laborious letter-by-letter processing. However, she showed normal language abilities and preserved copying, writing, oral spelling, letter naming, and aural recognition of spelled words.

Four features of MJ's performance are of particular relevance here: (1) MJ has no difficulty processing single letters, as indicated by her normal letter naming performance with stimuli displayed for very brief exposure durations (16msec); (2) despite (1), she has serious difficulties in processing multiple objects simultaneously, as indicated by her performance in the visual span task and the letter and line segment detection tasks, which showed a processing deficit characterised by a left-to-right gradient of difficulty for both absolute and relative positions in visual space; (3) she appears to have no difficulty accessing the orthographic input lexicon when presented with letter names for aural recognition, or when allowed enough time to process a visually presented letter string; and (4) despite (1) and (3), she does not have normal access to lexical orthographic representations and their meanings when stimuli are presented for too brief a time to allow for serial processing of the letter string. Indeed, we found no evidence of (partial) lexical or semantic access without corresponding recognition of the letters in a word: No signs of implicit reading were observed when the input stimuli were controlled for the relevant visual features; "implicit reading" was only obtained under conditions that allow sophisticated guessing.

How can MJ's pattern of performance be understood in terms of previous interpretations of LBL reading? Four broad classes of explanations have been offered for the LBL reading disorder: (1) a deficit at the level of the orthographic lexicon, (2) a deficit in accessing intact lexical orthographic representations, (3) a letter processing deficit, and (4) a basic perceptual deficit. We will briefly address each class of explanation in light of the results obtained with MJ.

Warrington and her collaborators (Warrington & Langdon, 1994; Warrington & Shallice, 1980) originally offered the interpretation that LBL reading is the result of damage to the orthographic lexicon (which the authors call the "visual word form system"). Damage to this system led patients to the strategic use of the spelling system as an alternative mode of word recognition. The adoption of this processing strategy results in a complete by-passing of the damaged orthographic lexicon in "reading." Presumably, LBL readers feed the individual letter names of a written word into this spelling system, which then functions in reverse to recognise the letter string as a word. Thus, as long as the spelling system is intact, reverse spelling would allow LBL reading to occur. The results we have reported for MJ are not inconsistent with this account of LBL reading: MJ named letters normally and she could spell perfectly well. The problem with this interpretation of LBL reading is not in fitting the facts but with the account itself. It is entirely mysterious what "reverse spelling" refers to: It is unclear how a processing system, which in the undamaged brain activates a string of graphemes in parallel from a lexical representation (see Caramazza & Hillis, 1990), would, in conditions of brain damage, function in reverse order and serially. Until the "reverse spelling" hypothesis is articulated in greater detail and independent justification is given for its presumed "reverse" functioning, we will have to withhold judgement on its explanatory value for LBL reading.

Patterson and Kay (1982; see also Bowers et al. 199b; Bub & Arguin, 1995; Feinberg, Dyckes-Berke, Miner, & Roane, 1995; Katz, 1980; Mimura, Goodglass, & Milberg, 1996) have argued that LBL reading results from (an unspecified) deficit in accessing an otherwise intact orthographic input lexicon. The authors maintain that orthographic context effects, such as those underlying the word superiority effect, and the observation of semantic priming indicate that LBL readers are able to gain lexical access even under conditions of impoverished input that does not allow for full recognition. This evidence is taken as an indicator of preserved lexical orthographic structure and processing. We agree with these authors that findings of this sort indicate preserved lexical orthographic knowledge. We also agree that such knowledge could be accessed through partial activation of lexical entries following presentation of an orthographic input that cannot be recognised overtly by the patient under limited exposure duration. However, we found no evidence in word-to-picture priming experiments that MJ was able to access semantic information unless she recognised the word (see Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990). In her case, above-chance performance in semantic categorisation tasks was most likely to be the result of sophisticated guessing. Whether a similar claim can be made for the cases cited in support of the lexical access deficit hypothesis of LBL reading remains an open question. And, in any case, this account leaves unexplained the relative letter position effects observed with MJ (see also Montant, Nazir, & Poncet, this issue).

Various authors have shown that some LBL readers present with a deficit at the level of letter processing (Arguin & Bub, 1994; Behrmann & Shallice, 1995; Howard, 1990; Rapp & Caramazza, 1991). Some have concluded that this deficit is causally linked to a patient's LBL reading (Arguin & Bub, 1993, 1994; Behrmann & Shallice, 1995; Montant et al., this issue), while others have viewed the letter processing deficit as functionally independent from it (Bowers et al., 1996a; Hanley & Kay, 1996; Kay & Hanley, 1991; Rapp & Caramazza, 1991). In the present investigation, we have taken MJ's perfect performance in letter naming at 100msec exposure and nearly perfect at 16msec exposure as an indication of preserved *single* letter processing. We agree with Behrmann and Shallice (1995, p. 452) who conclude that "... even in those cases in whom individual letter recognition is considered to be accurate, identification may well be slowed" and that more stringent assessment is needed before concluding that processing is normal. However, also in agreement with these authors, we believe that an account that interprets LBL reading as resulting from "slowed letter processing" is compatible with the interpretation that the reading disorder results from a more basic visual perceptual deficit that is not specific to letter processing. In support of the latter interpretation, we note that MJ showed comparable processing deficits in processing letter strings and simple line segments in time-constrained visual search tasks.

Finally, there is a class of interpretations that considers LBL reading to be the result of a basic perceptual deficit that is not specific to letter stimuli (Farah & Wallace, 1991; Friedman & Alexander, 1984; Kay & Hanley, 1991; Rapp & Caramazza, 1991). For example, Rapp and Caramazza (1991) reported the case of a LBL reader who, like MJ, showed a left-to-right gradient of processing difficulty for linguistic and nonlinguistic visual inputs alike. These authors suggested that LBL reading may result from a deficit that impairs the even allocation of processing resources across all spatial locations of a visual input. Because of this unequal allocation or deployment of resources, the encoding of information occupying progressively rightmost positions in the stimulus may be severely restricted. Consequently, repeated, serial fixations of letters (or other objects) becomes necessary in order to process an array of items for recognition. This account is consistent with the pattern of performance obtained with MJ.

Although the perceptual deficit explanation of LBL reading is consistent with the results reported for MJ, it fails to address the issue of why a presumably undamaged right hemisphere should show a basic perceptual processing deficit. One possible explanation might be that the right visual processing system does not allocate processing resources evenly across visual space resulting in inadequate processing of the rightmost part of stimulus strings.

However, this explanation is manifestly wrong. MJ showed the same performance for horizontally and vertically displayed words, and we could not induce a significant decrement in her abilty to process pictures of objects either in recognition or priming conditions[10]. Furthermore, the hemianopic control subject did not show a similar reading deficit. Thus, the hypothesis that the right-hemisphere visual processing system is somehow limited in its capacity to process visual strings must be considered with great scepticism.

The explanation that seems most compatible with the results we have reported for MJ is as follows: Visual information is processed normally by the intact right hemisphere but because this hemisphere (at least in some subjects) cannot interpret letters as graphemes it transfers visual form information to the left hemisphere. Since the units of interpretation are letters, this results in a serial scan and transmission of letter form information. (A similar process may occur with line segments if we assume that the response decision mechanism is located in the left hemisphere.) This process is necessarily slow and not compatible with the normal parallel functioning of word recognition in the left hemisphere, resulting in error-prone performance. Depending on the assumptions we make about the nature of the information transferred across hemispheres, and the nature of the degradation of this information as a consequence of the partial disconnection of the hemispheres, other explanations of LBL reading are possible.

The same set of evidence that has been invoked to indicate preserved lexical knowledge and its activation in the left hemisphere has also been invoked to argue for lexical activation and the representation of knowledge in the right hemisphere. In particular, in a series of reports Coslett and Saffran (1994a, 1994b) have argued that the "lexical" effects (semantic priming and good lexical decision performance) they obtained with their pure alexic patients are best understood as reflecting the residual reading capabilities of the right hemisphere (see also Coltheart, 1983; Zaidel & Schweiger, 1984; but see Patterson & Besner, 1984). This is an interesting possibility. However, if we were to agree with Coslett and Saffran, it would be unclear why MJ did not show comparable lexical effects to those observed with other LBL readers (see also Miozzo & Caramazza, this issue). Of course, it can be argued that there is considerable vari-

[10] However, there are two possible interpretations for this effect (or lack thereof). First, this could be a true effect, indicating that processing of pictorial information is appropriately processed in the right hemisphere and is not affected by damage to the mechanism responsible for the "LBL reading" deficit. Alternatively, this result may be a by-product of the object recognition task, which does not require exhaustive parsing of the visual information provided by the input stimulus. It may be possible to correctly identify an object on the sole basis of partial and even minimal information (e.g. a handle for a cup, or whiskers for a cat). In other words, it is possible that recognising a word or a string of characters is a more demanding task than recognising a picture of an object, in spite of the qualitative and functional equivalence of the two tasks. If this latter interpretation were true, then under conditions that prevent recognition on the basis of partial information on this task should also show the characteristic gradual decrement on the right. We are not aware of evidence addressing this issue, and further investigations are certainly needed.

ation among the reading capabilities of right hemispheres. And this possibility must be given serious consideration in the light of the results with split-brain patients (Baynes, 1992; Baynes & Eliassen, 1998; Gazzaniga, 1983; Gazzaniga, Smylie, Baynes, McCleary, & Hirst, 1984). The possibility that variation in performance across LBL readers reflects (among other things) different degrees of language specialisation in the patients' two hemispheres highlights the importance of administering the same (or compable) tests across individuals. However, it must also be emphasised that this hypothesis is extremely powerful and not easily testable, since we do not have a way of determining the strength of language lateralisation independently across individuals. Thus, it remains unclear when the failure to show implicit processing (as in the present case) would constitute evidence against the right-hemisphere reading hypothesis.

In conclusion, it would seem that Déjèrine's (1892) interpretation of pure alexia as a deficit reflecting the degraded transfer of information from a normal visual processing system in the right hemisphere to a normal language processing system in the left hemisphere continues to be the most plausible account of this class of disorders. Our findings support the view that LBL reading has (at least in MJ) a prelexical or "perceptual" basis, although there is not sufficient evidence to rule out additional impairments at higher levels of processing as possible sources of the deficit in other cases. The evidence we have reported can be entirely accounted for in terms of the serial transmission of information from the right to the left hemisphere and normal lexical processing in the left hemisphere. This evidence does not speak to the issue of whether there is (at least partial) lexical knowledge in the right hemisphere.

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