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Letter Dyslexia in a Letter-by-Letter Reader

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We describe a letter-by-letter patient who produced misreading errors in both letters in isolation and in words. All errors were visual in nature. We hypothesized an access deficit to the abstract visual representation of letters that prevents letter identification. This deficit could account for the patient's letter-by-letter behavior, since each letter constituted a potential identification problem. An access deficit, moreover, could also explain the patient's letter visual errors. In access processing, in fact, the letters sharing common structural features in their abstract representations were the ones more frequently mismatched. © 1996 Academic Press, Inc.

INTRODUCTION

Letter-by-letter dyslexics are patients who are able to read words only by identifying one letter at a time, from left to right, in a slow and laborious fashion (Warrington & Shallice, 1980). The monotonical increase in reading reaction times related to word length is often considered to be a distinctive character of these patients (Price & Humphreys, 1992).

From a psychological point of view, this dyslexia has been originally interpreted as an impairment of the visual word form system (Warrington & Shallice, 1980) that prevents the use of lexical representation in word reading and induces the patient to rely on a written-spelling strategy using letter name information.

In contrast, in the Patterson and Kay account (1982), the deficit is not located in the visual word-form system, but in the capacity to process the component letters of a word in parallel, so that the visual word form can be accessed only by means of a slow sequential letter identification. The account based on the impairment of the visual word-form system has been also recently challenged. Bub, Black, and Howell (1989) and Reuter-Lorenz and Brunn (1990) demonstrated the clear effect of orthographic context in the

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accuracy of letter recognition in letter-by-letter readers, confirming that these patients can still gain from a written word higher-level (i.e., lexical) information. Other reports have confirmed at least the relative preservation of the word-form system (Rapcsak, Rubens, & Laguna, 1990; Kay & Hanley, 1991; Hanley & Kay, 1992).

A further account of letter-by-letter reading identifies the locus of the deficit in the early stage of visual processing (Friedman & Alexander, 1984; Farah & Wallace, 1991). Letter-by-letter behavior would, thus, be considered the obvious manifestation of a more general visual impairment that affects the ability to rapidly process complex visual stimuli and not specific for orthographic material, as implicitly admitted by Patterson and Kay (1982). Arguin and Bub (1993), in contrast, tend to exclude a low-level visual–perceptual deficit, and consider letter-by-letter reading to be the result to a failure to quickly resolve the identity of letters.

As some authors acknowledge (Kay & Hanley, 1991; McCarthy & Warrington, 1990; Price & Humphreys, 1992), such conflicting accounts of letter-by-letter reading could simply reflect the possibility that letter-by-letter reading is more a compensatory strategy for different types of deficit than a homogeneous condition. The heterogeneity of this syndrome is further suggested by the different capacities that letter-by-letter readers show in single letter reading. Patterson and Kay (1982), for example, noted that their four letter-by-letter readers could be divided into two groups on the basis of their ability to identify single letters. While two of them often misidentified letters, the others did not. The existence of letter-by-letter readers without letter misidentification (also see Warrington & Shallice, 1980) would demonstrate that letter-by-letter reading does exist independently of difficulty in identifying letters. However, it should be acknowledged that an impairment of single letter reading was indeed present in all the Patterson and Kay patients (1982) and also in the Warrington and Shallice (1980) patients. Thus, since some degree of letter misidentification seems to represent the rule more than the exception in letter-by-letter readers, the possible relationship between letter misidentification and letter-by-letter reading should not be underestimated.

The aim of our study is to consider explicitly this relationship. We report a patient showing letter-by-letter dyslexia with a clear impairment in identifying both letters in isolation and as part of word. In fact, in both conditions he tended to misidentify the same letters, that is, in most cases, the ones sharing structural features (Tversky, 1977).

Patient's accuracy in reading single letters was lower than in reading letters in word, suggesting that he was facilitated by the orthographic context. This observation tendentially excluded interpretations that assume an impairment of the visual word form. Similarly, it did not completely fit with the hypothesis of a low-level visual perceptual deficit that affects the ability to rapidly process complex visual stimuli (such as words).

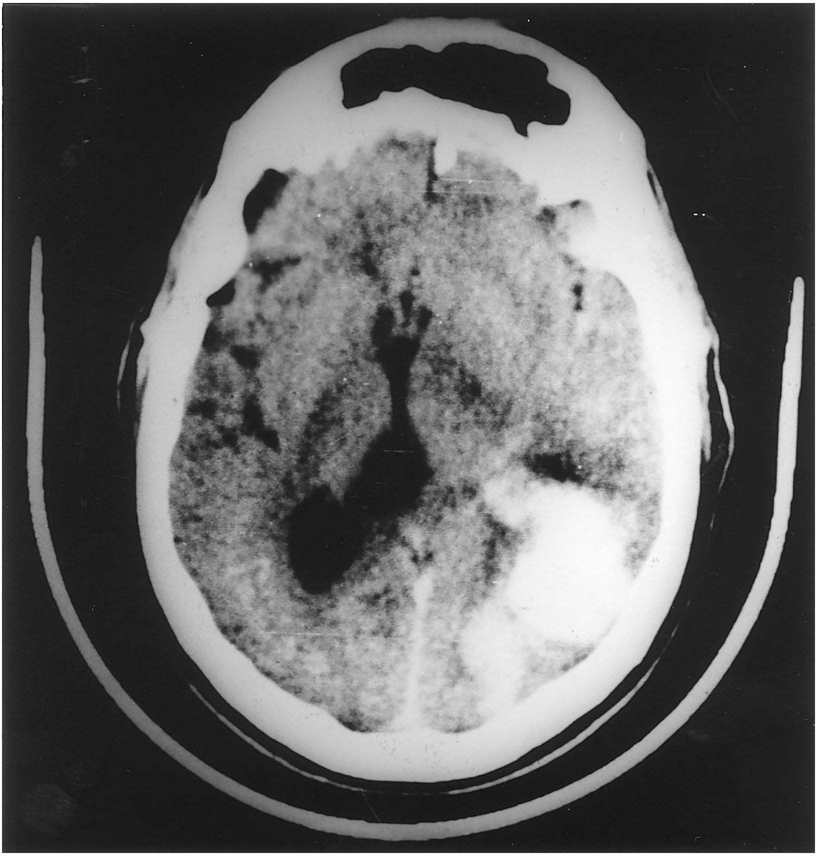

FIG. 1. CT scan showing left occipital parietal hemorrhage.

According to Arguin and Bub (1993), our patient's deficit could be interpreted admitting failures in letter identification. Our experiments were devised to define the nature of our patient's letter misidentification, specifically if the patient's deficit reflected a more general visual impairment or if it was specifically orthographic. We further explored whether the difficulty in identifying single letters might be causally related to patient's letter-by-letter behavior.

CASE REPORT

SP is a 73-year-old, right-handed patient, with 8 years of formal education. In August 1991 he suffered a stroke. At that time, he showed a right homonymous hemianopia with macular sparing and an alexia without agraphia. A CT scan showed a left occipital–parietal hemorrhage (Fig. 1). SP realized that he was no longer capable of reading shortly after the acute phase of his stroke. Forty days after the onset of illness, he wrote in his diary: ''I apologize to my reader, my brain has not healed yet; I can barely write, afterwards I can no more read what I have just written, I don't know the letters, neither mine, nor the ones printed on newspapers or books.''

In October 1991 he was admitted as an outpatient in our service. Neurological examination was negative, except for the visual field defect that he tried to offset by adopting compensatory exploration strategies. The patient was given a mental deterioration battery, exploring memory, abstract reasoning, and visual–spatial analysis, and a test battery for language examination (Miceli, Laudanna, & Burani, 1991). He scored within the normal range in all tests, except for naming and for tests involving reading.

Naming Tests

SP was impaired in confrontation naming. He named correctly 14/30 (47%) objects and 11/25 (44%) colors. Naming on description was slightly better (16/24, 67%).

Writing, Reading, and Lexical Decision

SP's writing skills were relatively preserved. He correctly wrote 41/46 (89%) words and 21/24 (88%) pronounceable nonwords by dictation. By contrast, he was able to read only 53/92 (58%) words and 27/45 (60%) nonwords. A significant difference was obtained between writing and reading scores (words, $\chi^2 = 14.03$, $p < .0002$; nonwords, $\chi^2 = 5.59$; $p < .0180$). SP adopted a letter-by-letter strategy in an explicit fashion, by spelling the letters serially, from left to right, before reading the whole stimulus word. In addition, reading the component letters of the words often proved to be difficult. SP seemed to find some obstacles in his spelling process. For example, he read ''anche'' [ALSO] in place of *banche* [BANKS], saying that he was not able to identify the first letter or he just skipped the letters he could not read, producing the correct response only after a number of trial-and-error attempts. The difficulty that SP met in identifying single letters was too evident to be reported only incidentally as a minor feature in his reading disorder. On the contrary, it seemed to be a major problem and perhaps one of the factors producing his letter-by-letter behavior. The stimuli were balanced for frequency, length, concretness, and grammatical class. The patient showed only a slight frequency effect.

He was also given a reverse spelling test consisting in identifying 50 words (three to nine letters long) spelled aloud by the examiner. He correctly identified 42 words. Since Italian native speakers are not familiar with spelling and reverse spelling tasks, this was considered to be a good result. Two age-matched control subjects, in fact, obtained comparable results (41 and 47 identified words).

SP's performance in reverse spelling was significantly higher than in read-

TABLE 1
SP's Performance on Reading, Writing, and Copy

		Reading			
		First response	Final response	Writing	Copy
(a) Words	Lowercase	582/797 (73%)	671/797 (84%)	149/162 (92%)	31/36 (86%)
	Uppercase	62/99 (63%)	72/99 (73%)		
(b) Nonwords	Lowercase		39/67 (58%)	55/64 (86%)	
(c) Letters	Lowercase		73/105 (70%)	184/190 (97%)	317/321 (99%)
	Uppercase		161/202 (80%)		

ing (reading vs reverse spelling, $\chi^2 = 10.19$, $p < .0014$), thus arguing against a ''central'' dyslexia (Shallice & Warrington, 1980). Reading 40 one-digit numbers, SP made three errors; two errors were made reading 18 two- and three-digit numbers.

The patient refused to perform an unlimited time lexical decision task claiming to be unable to ''read'' the items.

EXPERIMENTAL TESTING

Reading

Single letters. The patient was given 105 print lowercase single letters and 202 print uppercase single letters, each on a sheet of paper. No time limit for reading was requested. SP scored 70% correct for lowercase letters and 80% for uppercase letters (see Table 1c). The patient seemed to find some letters more difficult than others: for example, he consistently misidentified *b* (4/5), *g* (3/5), *h* (4/5), *l* (4/5), *p* (3/5), *q* (5/5); by contrast, he always read correctly *a, c, m, o, r, u.*

Words and nonwords. SP was asked to read 896 words (nouns, verbs, adjectives, and function words) of which 797 in print lower case and 99 in print upper case, and 67 pronounceable nonwords printed on paper sheets; the words were balanced for frequency and length. The patient was allowed unlimited reading time. SP's reading scores on words and nonwords are reported in Table 1 (a and b).

He was able to read correctly 73% print lowercase words and 63% print uppercase words. These data refer to his first response to the stimuli. Taking into account SP's self-corrections, the rate of correct reading raised to 84 and 73%, respectively. His reading of pronounceable nonwords was 58% correct for lowercase (uppercase nonwords were not administered). All SP's errors (but two perseverations) could be categorized as being visually similar to the target (see Appendix). No semantic errors were produced. Of the 126 errors that SP produced reading lowercase words, 79 were words and 45 neologisms. Of the 79 word errors, 46 could also be classified as morphological derivational errors (e.g., *mangiava* [HE WAS EATING] → ''mangiare'' [TO EAT]).

The patient's reading Reaction Times (RTs) appeared to be not strictly dependent on word length, as is usually the case with letter-by-letter readers (e.g., Price & Humphreys, 1992). The RT evaluation was extremely difficult because of the behavior of the patient while reading. In spite of the fact that he was clearly requested to give a response in any case, quite often he read, letter-by-letter, only a part of the stimulus or some letters, complaining that he was not able to identify one or some letters. Often he verbalized a particular difficulty with a

TABLE 2
SP's Reading Reaction Times (RTs) on the Items Correctly Read out of 30 Sample Words of Various Lengths

Word length (No. of letters)	Proportion correct	Mean RTs (sec)	Range (sec)
5	23/30	19.3	5–90
7	24/30	16.0	4–30
9	24/30	20.2	10–40

specific letter, producing many trial-and-error attempts. Examples of SP's reading RTs are reported in Table 2.

Thus, RTs seemed to be strongly influenced by the degree of difficulty that he found in identifying some of the letters constituting the word: e.g., *bomba* [BOMB] required 90 sec, while *conoscere* [TO KNOW] was read in 10 sec.

Nature of Single Letter Misidentifications

SP's letter misidentifications seemed visual in nature. In order to obtain direct evidence of our patient's tendency to confuse structurally similar letters, we adopted a slightly modified version of the confusion matrix used by Patterson and Kay (1982), based on Bouma's (1971) data. In this matrix, print lowercase letters are ordered in accordance with a visual similarity criterion. SP's reading errors in single letter reading were plotted on these matrices (Fig. 2).

As in the Patterson and Kay (1982) cases, most errors lay near the diagonal of the matrix, suggesting the important role of visual confusions. In fact, SP's errors mainly concerned visu-

	z	s	a	o	c	e	u	v	m	n	r	i	l	t	f	h	b	d	p	g	q
z									1												
s								1			1										
a						1				1											
o																					
c						1															
e													1								
u																					
v																					
m																					
n																1			1		
r															1						
i													3								
l																			1	1	
t																			1		
f																				1	
h																			1		2
b																		2	4		1
d																					1
p																					2
g																					2
q																					

FIG. 2. Visual confusion matrix for lowercase letters in isolation. Number of misidentifications is reported in boxes.

	p	b	t	d	ku	m	n	l	r	dz	dζ	tç	f	v	s	i	u	e/ε	o/∂	a
p		4	1		1						3		2							
b				5	1				2									1		
t											1			1						
d					1						1	1								
ku																				
m							1			1										1
n										1	1									2
l											2		1	1		3				
r													2		2					
dz																				
dζ													1							
tç																		2		
f																				
v															1		2			
s																		1		
i																				
u																				
e/ε																				2
o/∂																				
a																				

FIG. 3. Phonological confusion matrix for letters in isolation. Number of misidentifications is reported in boxes.

ally similar letters, or letters belonging to the same ''visual'' class (Patterson & Kay, 1982): Frequent confusions were *b–p, b–d, q–d, q–g,* (class ''loop on a stick'') and *l–i* (''ascenders''). Using a feature listing approach (Tversky, 1977), 20 errors out of 32 (62.5%) fell in groups of letters sharing common features, while 12 errors crossed the boundary between groups (Fisher Exact Probability = .039). Specifically, 14 misidentifications (44%) occurred among letters which belong to the class ''curved'' (12 among the ''curved and tailed'' and 2 among the ''curved and circular'' letters), 4 (12.5%) among letters in the ''vertical'' class, 1 in the ''angular'' class, and 1 in the ''arched'' ones.

A possibility that needed to be excluded was that letter confusions arose because of a phonological, rather than visual, mismatch. This seemed to be unlikely, since some of the most frequent confusions involved phonologically dissimilar letters (e.g., *q* was read /p/, /b/, /d/, /g/, but it was *never* read /k/). Yet, the possibility of a phonological mismatch was directly tested. We devised a ''phonological'' confusion matrix, structured by juxtaposing letters in accordance with pholonological similarity (Denes & Semenza, 1990). Our patient's errors in reading letters in isolation were plotted in this matrix (Fig. 3). It is evident that the pattern of errors is much more scattered with respect to the ''visual'' matrix (Fig. 2). Moreover, contrary to what is expected when a phonological deficit is present, the errors involving vowels (except two a–e confusions) crossed the boundary between vowels and consonants. Thus, the distribution of errors tended to disconfirm the hypothesis that SP's misreading could have a phonological basis.

Our results confirmed that the more plausible hypothesis to explain SP's letter misidentification was the visual confusion between letters, particularly evident with letters sharing structural features. Besides, the selective pattern of errors made implausible a deficit in letter name retrieval, which presumably ought to affect all the letters.

Undoubtedly, SP suffered from a visual perceptual deficit that impaired his ability in discriminating similar letters. His errors could be generated by a general, not letter-specific, visual perceptual deficit that would involve all the tasks in which a subtle visual discrimination is requested. Alternatively, his deficit might be specific for orthographic material. A series of

TABLE 3
SP's Performance on Visual–Perceptual Tests

Test	Proportion correct
Position discrimination (Warrington & James, 1988)	20/20 (100%)
Cube analysis (Warrington & James, 1988)	11/12 (92%)
Overlapping figures	6/6 (100%)
Simple copy of the Rey's complex figure	29/36 (81%)
Shape detection (Warrington & Taylor, 1973)	34/36 (94%)

visual–perceptual tasks were administered in order to obtain a general assessment of SP's visual–perceptual abilities. The tasks are reported in Table 3. SP demonstrated to perform at good level in all the tasks exploring the ability to reach the structural description of visual stimuli. However, he often produced visual errors (4 visual errors of 14 errors made on a 30-item list) when requested to identify objects (independently from his anomic problem). Even if he was not affected by a clear form of associative agnosia, we could not exclude some ''high-level'' difficulty in identifying objects. Similar deficit could impair letter identification. The possible locus of the letter misidentification within the letter visual processing was explored by means of specifically devised tasks.

Functional Locus of the Letter Misidentification

Simple matching task. The patient was given a 50-item matching task. In each item he was presented with print single letters written in upper- or in lowercase and then with two foils: the same letter and two structurally similar ones. The patient was requested to point to the letter corresponding to the stimulus. SP's accuracy in this task reached 100%.

Upper-to-lower matching task. In this task, the patient had to read an uppercase letter and then identify its lowercase form between two distractors. The task involved two conditions, one employing visually similar distractors (77 items), the other visually dissimilar ones (71 items) (Fig. 4).

Unlimited time of response was allowed. Results are reported in Table 4a.

In the condition implying a visual similarity between target and distractors SP was more error-prone (similar, 63/77 correct; dissimilar, 69/71 correct; $\chi^2 = 7.52$, $p < .01$).

Pointing. Two single-letter pointing tasks were administered, one with print lowercase letters (49 items) and one with print uppercase letters (56 items). The patient was requested to point to a letter spoken aloud by the examiner among the 21 letters of the Italian alphabet scattered on the desk in front of him. He was accurate in 84% of the items in lowercase letters and in 89% of the items in uppercase letters (Table 4b). SP made fewer errors in pointing

Similar condition	**D** **p d b**
Dissimilar condition	**D** **s m d**

FIG. 4. Two examples of upper- to lowercase matching task in ''similar'' and ''dissimilar'' condition.

TABLE 4
SP's Results on Letter Matching and Pointing

Task	Condition	Proportion correct
(a) Matching	Similar	63/77 (82%)
	Dissimilar	69/71 (98%)
(b) Pointing	Lowercase	41/49 (84%)
	Uppercase	50/56 (89%)

than in single letter reading (compare Table 1c), but the difference was not significant (lowercase: Reading 73/105 correct, pointing 41/49, $\chi^2 = 3.48$, $p = .059$; uppercase: Reading 161/202, pointing 50/56, $\chi^2 = 2.70$, $p = .096$). Interestingly, most pointing errors (lowercase, 5/8; uppercase, 5/6) concerned the visually similar letters that SP found difficult to read. For example, when asked to point to *i*, the patient pointed to ''l''; similarly, other errors were: *q* → ''p'', *b* → ''d'', *v* → ''U'', *d* → ''B'', *z* → ''S'', *b* → ''D.''

The results obtained in all these tasks were consistent with the hypothesis that a deficit arises whenever letter identification was requested, hence not only in reading, but also in uppercase/lowercase matching (Posner, Petersen, Fox, & Raichle, 1988) or in pointing tasks. In addition, the errors produced in matching and pointing tasks were similar to the ones produced in reading (confusions among structurally similar letters), in line with the hypothesis that the same deficit could subsume all these difficulties.

To explain SP's letter misidentification, we could hypothesize a deficit at the level of the stored structural representation of letters or, alternatively, a deficit in accessing an intact structural representation of the letters. The first possibility was, indeed, quite implausible, given the patient's ability to generate correct letters and words in writing (see Table 1). However, since the lexical representation for reading and writing could not be necessarily the same (Caramazza, 1988), we requested the patient to perform a letter imagery task, in which the patient gave a structural description of single letters spoken aloud by the examiner, or answered to specific questions about the structural characteristics of the letters. The patient was able to give exact information on 20/21 (95%) lowercase letters and on 53/56 (92%) uppercase letters (two controls scored at the same level: 97% vs 93% correct).

In conclusion, the results obtained were consistent with the hypothesis that SP was affected by a ''high-level'' visual perceptual deficit not necessarily limited to orthographic material. Simple letter misidentification could be explained on this base.

However, we could not yet draw a conclusion on the role that single letter misidentification played in producing letter-by-letter reading. In addition, the visual perceptual deficit that we hypothesized could not be the only visual perceptual deficit in SP. The data obtained up to now did not exclude the presence of an impairment of the nature hypothesized by Farah and Wallace (1991), that is the inability to process multiple shapes rapidly and/or in parallel (as letters in words require). In order to check this possibility, we devised a ''perceptual speed'' test similar to the one used by Farah and Wallace (1991), which required the rapid processing of serial visual stimuli.

Perceptual Speed Test

The test consisted of three subsets of stimuli, namely *numbers, letters,* and *figures.* (Fig. 5). In the *number* subset, a single digit (the stimulus) was on the left and five single digits were on the right, in a row.

Similarly, in the *letter* subset, a single letter was on the left and five single letters were on the right in a row. In the *figure* subset, the stimulus, consisting of a geometrical figure or a

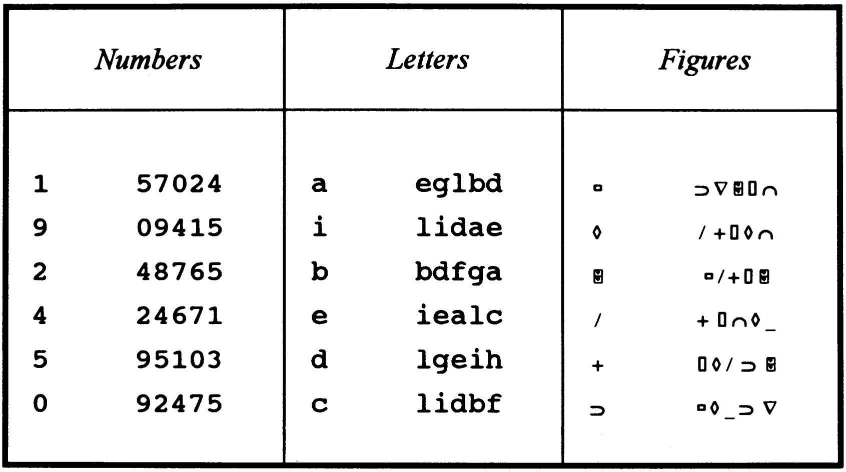

FIG. 5. Examples from the ''perceptual speed'' test.

meaningless picture, was drawn on the left; four visually similar alternatives were drawn on the right; only one of these was identical to the stimulus. In all the three subsets the target was present in 50% of the rows, in random position within the row. There were three columns of 10 rows each, plus one practice column in each subset. Each subset consisted of 30 items, preceded by 10 practice items. In the three subsets the task was to check, as rapidly and accurately as possible, the target.

Time was taken after completion of every 10-item column. An attempt to give the task with the same procedure used by Farah and Wallace failed because the patient, under time pressure, succeeded only in matching correctly a very low number of items. In fact, he clearly tended to prefer accuracy to the detriment of speed. The test was also administered to 2 normal subjects, ages 71 and 74. Results (accuracy and times of execution), obtained by SP and by the two controls, are reported in Table 5.

With regard to accuracy, SP and control subjects scored nearly 100% correct in all subsets. It could be objected that if the patient had been forced to change strategy and to perform the tasks with time limit, following the Farah and Wallace procedure, he possibly would have produced errors, confirming that misreading errors are related to the reduced ability in rapid processing of multiple shapes. Undoubtedly, our patient needed a longer time than controls to perform the three subsets, especially the letter subset, which he presumably tried to read (total time on the three 10-item columns of stimuli with respect to the two controls: *numbers,* 115 sec vs 60 and 60 sec; *letters,* 210 sec vs 60 and 72 sec; *figures,* 140 sec vs 60 and 65 sec). However, when the same tasks, without time pressure, were administered to a 68-year-old patient with a left parietal lesion, the time that the patient needed to perform the tasks was longer than that needed by controls (*numbers,* 115 sec; *letters,* 130 sec; *figures,* 155 sec), and the accuracy was quite low (*numbers,* 93%; *letters,* 68%; *figures,* 50%), even if the patient's reading ability was normal (she read 92 words and 45 nonwords rapidly and without errors). This finding suggests that these types of tasks may also be sensitive to deficits other than the ones affecting reading mechanisms.

In conclusion, the possibility that our patient's letter-by-letter behavior could rely at least in part on reduced abilities to rapidly process multiple shapes cannot be ruled out. However, other possibilities should be admitted. We had, in fact, direct evidence that SP suffers from a high-level visual perceptual deficit that affects letter identification. Finally, our hypothesis

TABLE 5
Accuracy and Time of Execution of SP and Two Control Subjects on a ‘‘Perceptual Speed’’ Task (See Text)

	SP		Control 1		Control 2	
Condition	Accuracy	Time (sec)	Accuracy	Time (sec)	Accuracy	Time (sec)
Numbers						
I	8/10	40	10/10	20	10/10	20
II	10/10	40	10/10	20	10/10	20
III	9/10	35	9/10	20	10/10	20
Total	27/30	115	29/30	60	30/30	60
Letters						
I	10/10	70	10/10	20	10/10	22
II	8/10	70	10/10	20	10/10	20
III	10/10	70	10/10	20	10/10	30
Total	28/30	210	30/30	60	30/30	72
Figures						
I	10/10	40	10/10	20	10/10	20
II	10/10	40	10/10	20	10/10	20
III	9/10	60	9/10	20	10/10	25
Total	29/30	140	29/30	60	30/30	65

is that SP’s dyslexia could depend, to a large extent, on single letter misidentification. While reading words, the reader cannot proceed automatically when a letter constitutes an identification problem and he will stop to try to solve the problem. If the problem involves several letters (or all the letters though with different degrees of severity) the resulting behavior will be a letter-by-letter reading.

If this hypothesis is correct, SP’s performance on single letter reading would predict his performance in reading words.

Relation between Single Letter Misreading and Word Dyslexia

Influence of letter visual similarity in reading words. We plotted on the previously described visual confusion matrix, the letter misreadings produced by SP in word reading. As Fig. 6 shows, although there are exceptions, the majority of errors lies near the diagonal, confirming a preferential involvement of visually similar letters.

It is worth noting that a higher number of confusions occurred between visually similar vowels in word reading, with respect to single letter reading. This could be explained by the fact that Italian language words end almost always with a vowel which, appropriately changed, assigns number and gender to nouns and adjectives. Hence, it is plausible that SP adopted the economic strategy of ‘‘guessing’’ the whole word as soon as he thought to have identified sufficient elements (i.e., a sufficient number of identified letters). In his laborious left-to-right processing, this often resulted in a wrong anticipation of the rightmost letter.

Correlation between number of errors produced on the same letters when read in isolation and as part of words. To obtain a quantitative measure of the correlation between the amount of errors produced in the same letters when written in isolation and as component letters of words, we computed on the whole samples of single letters and words read by SP the percentage of error produced on each letter of the alphabet in both conditions. The percentage of error was systematically higher on isolated letters than on letters in words (Fig. 7).

	z	s	a	o	c	e	u	v	m	n	r	i	l	t	f	h	b	d	p	g	q
z																					
s										1	12		2	2	1						
a				21		49	2					1									
o						15	1					3									
c								2		1			1						1		
e							6					18									
u												1									
v										1	1							1		2	
m														1							
n											2			6							
r													1	2	4					1	
i													2	1							
l														5							
t															3			1	3		1
f																					
h																					2
b																		9	5		
d																			3		3
p																				3	1
g																					1
q																					

FIG. 6. Visual confusion matrix for letters in words. Number of errors is reported in boxes.

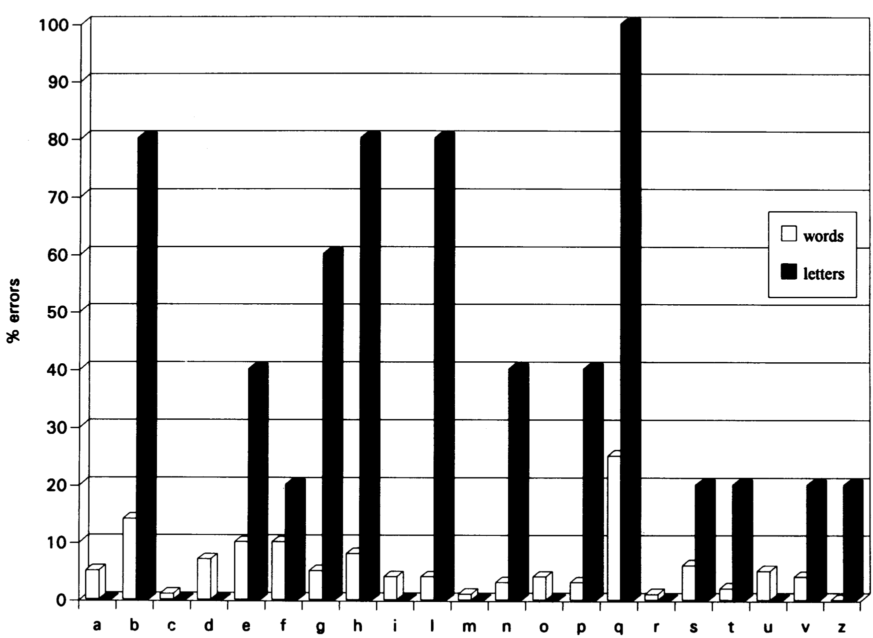

FIG. 7. Percentage of letter misidentification reading words and letters in isolation.

These values were compared by means of Spearman's correlation test. The analysis indicated a significant positive correlation between the percentages of errors produced in the two conditions ($r_s = .4493$, $p < .05$).

Relationship between accuracy in word reading and presence of ''difficult'' and ''easy'' letters. To evaluate whether the patient faced a greater difficulty in reading words that incorporate letters that he could not identify reliably when presented in isolation, with respect to words formed by letters that he identified easier we performed the following post-hoc analysis. A score was assigned to each letter on the basis of the patient's single letter reading errors. The score ranged from zero (5/5 letters correctly identified) to five (0/5 letters correctly identified). The letter scores were used to compute a ''difficulty score'' for each of the 797 lowercase words read by SP. This ''difficulty score'' was expressed by the ratio between the sum of the scores of the letters forming each word and the number of letters themselves. We considered the two tails of the score distribution: the 53 words that obtained a difficulty score of zero and the 53 ''most difficult'' words (difficulty score $\geq$1.75). SP made four errors on the ''easiest'' words, but he made 13 errors reading the 53 words with the highest scores ($\chi^2 = 5.67$, $p < .017$). Thus, patient's performance on word reading proved to be predictable from his letter reading. In fact, these two types of evaluation demonstrated that:

(a) the patient tended to produce the same visual errors on the same letters independently of the condition of presentation (in isolation or as component part of words);

(b) even though SP was generally facilitated by the context when reading letters in words, a positive correlation exists between the percentage of errors produced on the same letters when presented in isolation and as a part of words;

(c) the accuracy in word reading seemed to be influenced by the accuracy obtained on the component letters of the words when read in isolation.

DISCUSSION

A deficit in accessing the structural representations of letters proved to be the most plausible explanation for SP's single letter reading deficit. Single letters are misread because of a high-level perceptual disorder, that is, a deficit in matching the product of visual analysis to the relevant mental image. In particular, SP's visual deficit was supposed to be located at the level in which the structural description of a meaningful visual stimulus has to be matched with the corresponding mental representation. Thus, our data support the hypothesis that a reading disorder might be interpreted admitting a visual deficit not necessarily specific for orthographic material.

We also advance the hypothesis of a causal relationship between single letter and word dyslexia. The experimental findings confirmed that the difficulties found in single letter reading may predict the difficulties in word reading.

In particular, in agreement with Arguin and Bub (1993), our hypothesis is that SP, in spite of his ability to elaborate the letter visual shape, was unable to reach its abstract structural representation (being the structural representation itself unimpaired) which is a necessary step in allowing letter identification. The abstract representations of letters which share some structural features are more sensitive to access deficit and this could account for the nature of reading errors, i.e., confusion among structurally similar letters. For example, the *g* representation shares some structural features with the *p* representation, so that mismatches between the two letters have more chances to occur, while *g* has less probability to be confused with, for example, *l*. The access deficit could be further specified as the difficulty to match the letter shape, although correctly analyzed, to its abstract structural representation, choosing among structurally similar alternatives. In other words, the more structural features in common, the more chances for the letters to be confused. If we admitted for SP an access deficit involving all the letters, but particularly evident for the structurally similar ones, we could also explain his reading behavior: reading always slowly, letter-by-letter (since each letter constitutes a potential identification problem), with longer pauses and errors on structurally similar letters which are more liable to be confused.

Within the framework of the interactive activation model of reading (IAM) (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), SP's dyslexia could be explained by a single deficit, which would lie either at the feature level or between the feature and the letter level. SP's good performance on tasks which do not require the explicit identification of the stimulus, such as the letter copy task (Table 1) and visual–perceptual tasks (the ''figure'' subset used some letter features as stimuli; Fig. 5), would suggest that the feature level is unimpaired. If this were the case, some noise in the flow of information between the feature and letter levels could generate confusion during the activation of (intact) letter detectors. It is plausible that this confusion would especially affect visually similar letters, as in SP's case, because these letters share some feature detectors. Excitatory and inhibitory messages originating from inappropriate activation of letters would then generate wrong word-level activation. The advantage that SP found in reading letters in words with respect to letters in isolation (see Fig. 7) could be explained by the positive feedback that letters in words receive from the word level, a top-down effect that is obviously lacking when the stimulus is an isolated letter.

A key feature of IAM is parallel processing: a region of space as large as at least a four-letter word is processed simultaneously. Another assumption of IAM is that the temporal integration among the pattern of activated nodes occurs slowly enough that brief activations may come and go without necessarily becoming accessible for purposes of responding. This happens in order to eliminate the weakly activated nodes only partially consistent with the target. A longer letter reading time increases the probability that the strongest letter node (i.e., the most consistent with the perceived features) reaches the highest activation level and the weaker nodes decay. If our patient suffered from weakly activated letter nodes (with a consequently difficult temporal integration), he would plausibly try to optimize his difficult visual perception of letters by facing one problem at a time, i.e., one letter at a time. The use of a serial reading technique minimizes the temporal integration problems, allowing enough time for each letter node to be activated.

Although the hypothesis about the heterogeneity of letter-by-letter syndrome is quite plausible and largely accepted (but see Shallice, 1988), we agree with Arguin and Bub (1993) that some differences observed among patients might be considered quantitative rather than qualitative in nature. Letter-by-letter reading may be considered to be a syndrome ranging from mild to severe forms of access deficit to the letter abstract representations. In the first case, patients' compensatory strategies would be sufficient to prevent letter misreading, thus producing only a letter-by-letter behavior, as Arguin and Bub's patient did. In the more severe forms, an example of which could be SP, letter misreading would occur, more or less evidently, in addition to letter-by-letter behavior. Unfortunately, information on letter-by-letter readers' ability in processing single letters, which could be crucial for further discussion of this hypothesis, is only occasionally reported. We hope that this aspect will not be neglected in future reports.

APPENDIX

Stimulus	Response
svolge [he unwinds]	svuo *nw*
nocciola [hazelnut]	rocciola *nw*
agguato [ambush]	appunto [note]
muffa [mould]	matta [mad]
basata [based]	dasata *nw*
qualcosa [something]	quainosa *nw*
dilatava [he extended]	dilatato [extended] *morph*
quindi [hence]	puindi *nw*
inventata [invented]	inventate *morph*
chiunque [anyone]	chiudua *nw*
frecce [arrows]	frecco *nw*
quando [when]	durato [gone on]
anche [also]	acqua [water]
mutato [changed]	metato *nw*
camice [white overall]	camino [fireplace]
mandorla [almond]	mandorìa *nw*
librerie [bookshops]	lidrerìa *nw*
ove [where]	oce *nw*
quassù [up here]	quallè *nw*
banche [banks]	anche [also]
bando [proclamation]	tanto [much]
detestare [to dislike]	desertare *nw*
regalato [given]	regalata *morph*
vicende [events]	vicanda *nw*
sistemare [to arrange]	sistemate [arranged] *morph*
insulti [insults]	insulte *nw*
volpe [fox]	volge [he turns]
damigiane [demijohns]	damigiana [demijohn] *morph*
tramonta [it goes down]	tremora *nw*
falci [sickles]	falce [sickle] *morph*
invano [in vain]	indano *nw*
stelle [stars]	stella [star] *morph*

Stimulus	Response
fruga [he rummages]	truga *nw*
tranne [except]	tratte [sections]
bensì [but]	dense [thick]
corvo [crow]	corno [horn]
allarmata [alarmed]	allarmo [I alarm] *morph*
torture [tortures]	tortura [torture] *morph*
cenare [to have supper]	canare *nw*
giusti [right]	riusti *nw*
sedile [seat]	sèbile *nw*
ferire [to wound]	feriva [he wounded] *morph*
sembro [I look like]	sembre *nw*
avverte [he informs]	avverti [you inform] *morph*
spingo [I push]	spinga *morph*
mangiava [he ate]	mangiare [to eat] *morph*
scendeva [he was going down]	scandeva *nw*
cercavano [they were looking for]	carcavano *nw*
rise [he laughed]	riso [laughter]
viceversa [on the contrary]	riceveranno [they will receive]
stacca [he takes off]	stucco [stucco]
risultava [it resulted]	risultano [they result] *morph*
nutrivano [they nourished]	nutriva [he nourished] *morph*
rapidi [quick]	rapide *morph*
inferiori [lower]	inferiore *morph*
onda [wave]	onde [waves] *morph*
guanti [gloves]	quanti [how many]
riga [line]	riva [shore]
matta [mad]	matte *morph*
giornale [newspaper]	giornata [day]
rossa [red]	rosso *morph*
mesi [months]	mesti [sad]
povera [poor]	povero *morph*
rispondi [you answer]	risponde [he answers] *morph*
vive [he lives]	viva *morph*
culto [worship]	sculto *nw*
sosta [breack]	sorta [kind]
bando [proclamation]	banco [desk]
scopo [aim]	scopa [brush]
tigre [tiger]	tigro *nw*
colpa [fault]	colta [educated]
gusto [taste]	gurto *nw*
clima [climate]	crima *nw*
torto [wrong]	torno [I come back]
bomba [bomb]	bombe [bombs] *morph*
costo [cost]	carto *nw*
belva [wild beast]	delva *nw*
lampo [lightning]	lembo [edge]
pompa [pump]	pompe [pumps] *morph*
bianco [white]	bianca *morph*
paesi [countries]	paese [country] *morph*
mesi [months]	mese [month] *morph*
fratello [brother]	fratelli [brothers] *morph*

Stimulus	Response
razze [races]	razza [race] *morph*
pagata [payed]	pagato *morph*
pesava [he weighed]	perava *nw*
sedette [he sat]	sebette *nw*
sembro [I look like]	sembre *nw*
ripetendo [repeating]	ripetenti [repeating] *morph*
catene [chains]	catena [chain] *morph*
alzi [you raise]	alze *nw*
teme [he is afraid]	temo [I am afraid] *morph*
gambe [legs]	gamba [leg] *morph*
diventato [become]	diventa [he becomes] *morph*
giusto [right]	giorno [day]
sullo [on the]	sulla *morph*
chiunque [anyone]	chiunche *nw*
odia [he hates]	obia *nw*
guarire [to recover]	guariva [he recovered] *morph*
rapidi [rapid]	sapidi [sapid]
sensibile [sensitive]	sensibili *morph*
volgare [vulgar]	volgere [to turn]
modesto [modest]	moderno [modern]
lusso [luxury]	lutto [mourning]
progressi [progresses]	progresso [progress] *morph*
difficile [difficult]	dirricile *nw*
scuola [school]	giòla *nw*
mesi [months]	meri *nw*
ville [villas]	villa [villa] *morph*
librerie [bookshops]	lepre [hare]
giace [he lies]	gioca [he plays]
banche [banks]	panche [benches]
tranne [except]	telle *nw*
bensì [but]	pensì *nw*
bottiglia [bottle]	bollicèa *nw*
polvere [dust]	polveri [dusts] *morph*
mangiava [he was eating]	mangiare [to eat] *morph*
cercavano [they were looking for]	carcavano *nw*
valga [he is worth, conjunctive]	volvo *nw*
tranne [except]	tratte [pull]
gambe [legs]	gamba [leg] *morph*
bombe [bombs]	bomba [bomb] *morph*
nocciola [hazelnut]	dasata *nw pers*
stelle [stars]	stella [star] *morph*
fruga [he rummages]	rugia *nw*
tranne [except]	stella [star] *pers*

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