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SINGLE-CHARACTER PROCESSING IN A CASE OF PURE ALEXIA

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Abstract—The processing of single characters in a pure alexic patient was studied in an attempt to identify the impairment responsible for his reading disorder. Observations from Experiments 1 to 4 suggested a deficit of *identification* of alphanumeric stimuli without any impairment affecting the elaboration of a structural description of visual stimulation. Experiment 5 indicated that the identification disorder results from a defect in the selective processes—activation and/or inhibition—that must come into play for achieving an appropriate match between a structural description of the stimulation and representations of the identities of known stimuli. The possible implications of this deficit in single-character identification for word reading are discussed.

INTRODUCTION

Pure alexia is a neurological disorder the characteristic behavioral features of which are very slow, but, in general, accurate reading, and massive effects of word length on performance. Thus, pure alexics appear to decode words as a sequence of isolated letters, without any access to the holistic process that is observed in the normal reader [24, 50]. Published results indicate that the effect of word length on reading times varies greatly from one patient to the other, but that, with very few exceptions, it is above—and sometimes far above—a 1-sec increase for every additional letter [8, 13, 17, 27, 44, 47, 48, 52, 68].

Resting mostly on anatomical evidence, early interpretations of pure alexia held that the disorder was the result of a disconnection preventing access of visual information from the occipital cortex to the language center involved in the interpretation of written material [15, 20]. In agreement with this view, anatomical findings indicate that pure alexia is, in most cases, associated with a lesion that involves the left occipital area and the splenium of the corpus callosum [14, 22]. As a general rule, Damasio and Damasio [14] stated that the crucial anatomic correlate of alexia was a lesion of the paraventricular white matter of the left occipital lobe, capable of compromising both interhemispheric and intrahemispheric visual pathways (p. 1573).

Although consistent with anatomical observations, the disconnection account of pure alexia is not explicit with respect to the cognitive operations that are perturbed in this disorder. For this reason, authors have more recently attempted to determine the level of visual information processing that is affected in pure alexia. Numerous cognitive explanations have been presented to account either for pure alexia as a syndrome or for the

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reading impairments demonstrated by specific alexic patients. These hypotheses, which may be broadly divided into three categories, are briefly described below.

One explanation recently proposed by RAPP and CARAMAZZA [47] is that a deficit affecting the low-level perceptual processes responsible for the elaboration of a structural description of the input may be responsible for the reading deficit. Obviously, a disorder which prevents subjects from deriving an appropriate description of the shape of the stimulation presented will impair reading. Specifically, these authors hold that the impairment suffered by their patient occurs at the levels of putative retino-centric and stimulus-centered feature representations. That is, they assume decreasing left to right gradients in the accuracy of feature representations across each of these spatial reference frames. This impairment of feature representation is assumed to prevent normal access to lexical representations and force the patient to slowly decipher each letter in turn in order to read a word.

Other authors have focused on the slowness of letter identification in pure alexics, as well as on their high propensity to commit letter identification errors that are morphologically close to the target. These features of pure alexia have been noted on repeated occasions [8, 9, 11, 13, 17, 19, 23, 27–31, 44, 47, 48, 52, 55, 56, 68]. On the assumption that multiple letters must be rapidly identified before words can be read, it has been suggested that the systematic association between letter processing difficulties—as inferred in some measure by the magnitude of the effect of word length on performance—and the word reading disorder in pure alexia is, in fact, the manifestation of a causal relationship [17, 19, 28, 29, 31, 48].

A number of different accounts for pure alexia are based on this assumption. Thus, according to KINSBOURNE and WARRINGTON [28, 29], the reading disorder seen in pure alexia arises from a difficulty in encoding many separate visual forms simultaneously, a disorder they call simultanagnosia (see also Refs [17] and [31]). This hypothesis was called into question however by observations reported by WARRINGTON and RABIN [67] and WARRINGTON and SHALLICE [68]. Indeed, these latter results suggest a double dissociation between simultanagnosia and pure alexia, which is inconsistent with an account of the latter disorder on the basis of the former. Another account, which has more recently been proposed by FRIEDMAN and ALEXANDER [19] and by REUTER-LORENZ and BRUNN [48], is that pure alexic patients suffer from a deficit in identifying individual letters as well as multiple letters, which forces them to read words in a slow letter-by-letter manner. According to FRIEDMAN and ALEXANDER [19], pure alexic patients have a generalized disturbance in the automatic identification of visual input, while REUTER-LORENZ and BRUNN [48] argue, more specifically, that these patients are unable to rapidly form abstract character representations from letter shapes.

Another type of account of pure alexia proposes that the reading impairment is due to a disorder affecting word-level processing. According to WARRINGTON and SHALLICE [68], pure alexics suffer from damage to the word-form system, which makes impossible the use of visual lexical representations for word recognition. They define the word-form system as a functional module responsible for the parsing of letter strings into familiar units and the visual categorization of these units. A related account, which also assumes a deficit at the level of whole word processing, has been proposed by PATTERSON and KAY [44] and has more recently been held by KAY and HANLEY [27]. These authors claim that letter-by-letter reading arises from a disconnection between peripheral letter analysers and whole-word representations. This disconnection is assumed to prevent the normal spatially parallel mapping of abstract letter identities onto word-level representations, such that access becomes slow and sequential.

In view of the multiplicity of the cognitive accounts that have been provided for pure alexia, one possible inference is that the locus of functional damage responsible for the

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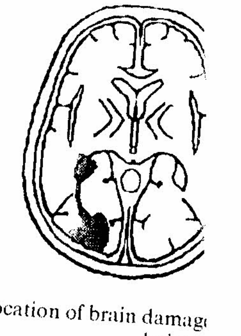

Fig. 1. Location of brain damag
lesion

disorder varies from patient to patient and that no uniform account of the syndrome can be developed (cf. Ref. [27]). It is important to emphasize, however, that at least one fact seems to apply to all cases of pure alexia, i.e. the slowness with which the patients decode letters, either as single units [19, 48] or as multiple forms (indicated by the hallmark of the disorder, the massive effect of word length on reading performance). One important clue to the syndrome, therefore, must lie in a more precise account of the constraints on processing at this early level in the system.

This paper attempts to determine the processing disturbance which is responsible for the general slowness of letter-by-letter reading in an alexic patient, D.M. We will then discuss the relationship between the deficit affecting the identification of single letters and the more prominent limitations on word reading that characterize the syndrome.

CASE REPORT

D.M. was a right-handed undergraduate student in engineering at the time he suffered from a ruptured arterio-venous malformation of the left-posterior cerebral artery in February 1990. Neurosurgery for excision of the arterio-venous malformation was performed in March 1990. Based on the surgical report and CT scans, Fig. 1 illustrates the brain area which was damaged. It may be seen that the area involved roughly corresponds to the lesion typically observed in pure alexies [14, 22]. D.M. shows no evidence for callosal damage, an observation confirmed by DAMASIO and DAMASIO [14] in a number of cases. D.M.'s main behavioral complaints were of a complete right-homonymous hemianopia, mnestic difficulties, and reading problems. Clinical testing using common words (frequency above 50 per million [18]) between 4 and 7 letters in length revealed letter-by-letter reading. Thus, D.M. showed a linear increase in naming latencies of about 500 msec per additional letter in a word. It should be pointed out that this reading rate is somewhat faster on average than that of most other pure alexics reported in the literature. WARRINGTON and SHALLICE's [68] patient R.A.V., who appears to be the quickest letter-by-letter reader so far reported, also showed increases in reading times of about 500 msec per additional letter in a word. No other language deficit was observed in D.M. The experiments reported here were performed with D.M. between July and December 1990. D.M. was 24 years old at the time of testing.

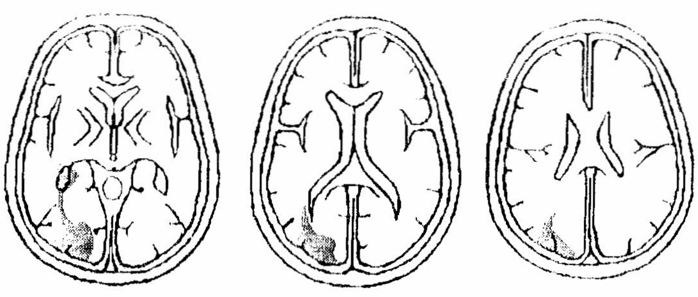

Fig. 1. Location of brain damage in D.M., illustrated by the shaded area. Only the slices on which a lesion was visible on the CT scan are presented.

EXPERIMENTAL INVESTIGATIONS

The basic hypothesis that we intend to pursue is that pure alexia may be the result of a deficit in *identifying* alphanumeric information, without the necessity of any concomitant disorder affecting the capacity of the patient to determine the shape of these stimuli, i.e. the elaboration of a structural description of the visual input. The aim of the experiments reported here is to evaluate this claim by specifying the impaired processing level responsible for the abnormal performance of D.M. in processing either a single alphanumeric character or a sequence of such symbols. We will demonstrate, in Experiments 1, 2 and 3, that D.M.'s pure alexia dissociates from disorders affecting low-level perceptual processes. We will then present positive evidence for a deficit affecting the identification stage in single-character processing (Experiment 4). Finally, Experiment 5 will provide indications as to the specific processes responsible for this identification disorder.

EXPERIMENT 1

One type of impairment that may be considered as a potential cause of a reduced rate of letter processing in reading is a low-level perceptual deficit affecting the mechanisms responsible for encoding visual features. As indicated above, RAPP and CARAMAZZA [47] have argued that such a disorder may account for the poor reading performance of the alexic subject they studied. Experiment 1 will examine the possibility of a visual feature processing deficit by having D.M. and a group of normal controls search for a visual target differing from distractors by a single feature—orientation—under normal and degraded exposure conditions. The use of a degraded exposure condition was prompted by the need to provide a stringent test of feature encoding in D.M.

In this experiment as well as in Experiments 2 and 4, subjects were required to indicate whether a predetermined target was present or not in an array made of a variable number of items. The result of main interest in these three visual search experiments will be the effect of the number of items on response times (RTs).

In Experiment 1, it is expected, on the basis of the literature on visual feature search [3, 5, 43, 59, 61], that the normal controls will be able to detect the target by a process of spatially parallel examination of all the items presented. In terms of performance, this implies the absence of any significant effect of the number of items displayed on RTs—at least on target-present trials—and an additive effect of degraded exposure on RTs [53]. Any deviation from this pattern of performance in D.M. should be interpreted as a deficit in low-level feature processing.

Method

Subjects. D.M. and five well trained normal control subjects, matched to D.M. for age, education level, and handedness took part in this experiment.

Materials and stimuli. The experiment was run on a Macintosh Plus microcomputer and was controlled by PsychLab software. A microphone, linked to the computer, was used to register the verbal yes/no response that was required from subjects on each trial.

The target subjects had to search was a horizontal bar. On each trial, a variable number of distractors were presented. Distractors were vertical bars. Stimuli were black on a white background and their size was 2 mm wide × 7 mm long. They were displayed at randomly selected locations within a 4 × 4 location array which was vertically centered with ocular fixation. The horizontal and vertical distances between each location in this array was 1 cm. The stimulus array was located to the left of a central fixation dot (4.5 mm in diameter) which was visible for 1.5 sec before the onset of the search stimuli. The smallest horizontal distance between this fixation point and any given stimulus in the search array was 1 cm. The search stimuli remained visible until the subjects responded.

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Results and discussion

Figure 2 shows the average R
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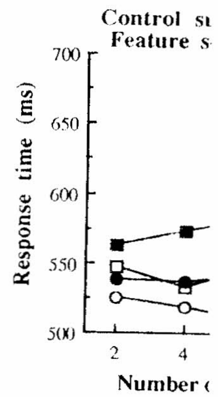

Fig. 2. Average RTs observe
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On some trials, the stimulation was presented under normal (unmasked) conditions and, on others, a mask of random black dots, of about 30% density, was superimposed over the entire stimulus array.

Procedure. The task required subjects to indicate verbally (yes/no response) as rapidly as possible while avoiding errors, whether a horizontal bar was present in a stimulus array made of 2, 4, 6 or 8 items. One target was present on half the trials and none in the other half. The mask described above was superimposed over the stimulus array in half the trials.

The experiment therefore involved three factors: target (two levels: present or absent), masking condition (two levels: masked or unmasked), and the number of items displayed (four levels: 2, 4, 6 or 8). The experiment was run in six separate blocks of 64 trials each. Four trials in each condition were distributed randomly in each block. Subjects were seated at approx. 40 cm from the display screen.

A few trials had to be eliminated due to failure of the subject's verbal response to trigger the microphone. This was the case on 1.3% of the trials for D.M. and on 2.0% of the trials for the control subjects. These trials were excluded from data analyses.

Results and discussion

Figure 2 shows the average RTs of D.M. and of the control subjects during the search for a feature target under masked and unmasked conditions. Linear regressions of RTs as a function of the number of items displayed are shown separately for each condition in Table 1. The error rates observed in this experiment are presented in Table 2. The correlations between RTs and error rates were not significant (0.34 for D.M., 0.13 for controls), indicating the absence of a speed–accuracy trade-off.

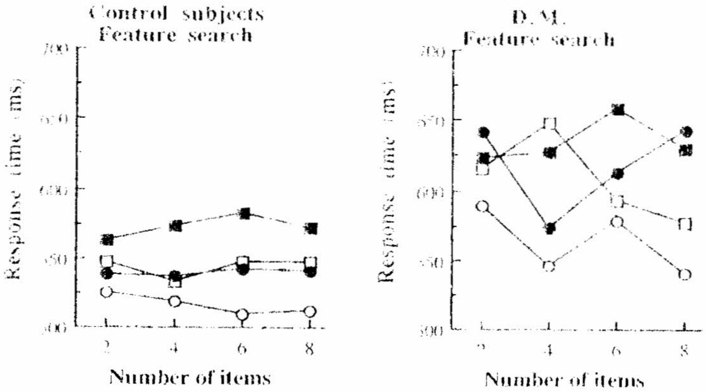

Fig. 2. Average RTs observed in the control group and D.M. in each condition of Experiment 1 — feature search. The panel on the left shows results of the normal controls and that on the right the results of D.M. Circles = unmasked displays. Squares = masked displays. Empty symbols = target-present trials. Filled symbols = target-absent trials.

An ANOVA performed on the average correct RTs observed in the control subjects only revealed main effects of masking [$F(1, 4) = 13.2$; $P < 0.05$] and of target presence [$F(1, 4) = 57.9$; $P < 0.005$]. Other main effects and interactions were not significant—all F values were close to or below 1. The main effect of masking indicated longer RTs if the stimulus array was masked (average = 558 msec) than unmasked (average = 528 msec) and the effect of target presence indicated longer RTs on target-absent trials (average = 556 msec) than on target-present trials (average = 530 msec). Regression analyses presented in the upper part of Table 1 indicated effects of the number of items which were about null in all conditions. No significant effect was seen in the analysis of the error rates observed in the normal controls.

Table 1. Linear regression analyses of RTs as a function of the number of items displayed in the feature search task (Experiment 1). The intercept, slope and 95% confidence interval for the slope (lower/upper limits) of the linear regression function (all given in msec) as well as the percentage of variance it accounts for are presented separately for each condition. Note that, for D.M.'s results, the confidence interval column indicates whether his slope falls within (−) or outside (+) the interval established for the normal controls in the corresponding condition

Subjects	Mask	Target	Intercept	Slope	95% confidence interval	% of variance
Controls	Present	Present	540	0.7	−7.2/8.7	7
		Absent	564	1.7	−5.9/9.4	35
	Absent	Present	529	−2.5	−12.1/7.0	80
		Absent	536	0.7	−8.5/9.8	51
D.M.	Present	Present	651	8.6	+	51
		Absent	621	2.6	−	18
	Absent	Present	591	−5.6	−	36
		Absent	607	2.2	−	3

Table 2. Error rates (in %) observed in the feature search task (Experiment 1)

Subjects	Number of items	Masked—target present	Masked—target absent	Unmasked—target present	Unmasked—target absent
Controls	2	1.7	0.0	1.8	2.7
	4	1.7	4.2	0.9	1.7
	6	3.6	0.8	2.6	2.6
	8	3.5	0.8	2.5	1.7
D.M.	2	0.0	0.0	0.0	4.3
	4	8.3	4.2	0.0	0.0
	6	0.0	0.0	0.0	0.0
	8	4.2	0.0	0.0	0.0

The ANOVA performed on D.M.'s results used individual trials as independent samples, as all the other analyses performed on his data in the subsequent experiments. The observations from the feature search task indicated main effects of masking condition [$F(1, 359) = 11.0$; $P < 0.005$] and of target presence [$F(1, 359) = 18.5$; $P < 0.001$], as well as interactions of mask × number of items [$F(3, 359) = 3.2$; $P < 0.05$] and of target × number of items [$F(3, 359) = 2.8$; $P < 0.05$]. Other main effects and interactions failed to reach significance. RTs were longer if the stimulus array was masked (average = 621 msec) than unmasked (average = 590 msec) and RTs were longer on target-absent (average = 626 msec) than on target-present trials (average = 586 msec). Simple effects of the number of items on masked [$F(3, 359) = 1.1$; n.s.] and unmasked [$F(3, 359) = 1.0$; n.s.] displays as well as on target-present [$F(3, 359) < 1$] and target-absent [$F(3, 359) < 1$] trials were not significant. This outcome is consistent with the slopes of the linear regression functions presented in the lower part of Table 1, which revealed very weak or negative effects of the number of items on RTs. All slopes observed in D.M. fell well within the 95% confidence interval of slopes seen in the normal controls, except for masked target-present trials, where D.M.'s slope was negative. Analysis of the error rates suggested some variation in accuracy as a function of the condition, but this effect did not reach significance [χ^2 (15) = 17.5; n.s.].

Except for producing slightly longer RTs than the normal controls, the pattern of effects shown by D.M. in the feature search task was very similar to that seen in the control subjects. Worth noting, both D.M. and the normal controls showed no significant increase of RTs with the number of items on target-present trials, and the effect of masking was additive and of about the same magnitude. These observations suggest that D.M.'s feature processing is spatially parallel and that it is not particularly affected by degradation of the input. It therefore appears that visual feature encoding is normal in D.M. and that the origin of his very slow letter-by-letter reading lies further along in the visual processing stream.

The perfomance observed in D.M. in Experiment 1 differs markedly from that reported by RAPP and CARAMAZZA [47]. Their patient, in a feature search tasks, exhibited a significant increase of RTs as the number of items displayed increased, and this result occurred even though masking was not used in their experiment. The lack of any important discrepancy between D.M.'s results and those of the control subjects clearly underscores that a feature processing deficit is not a necessary condition for pure alexia.

EXPERIMENT 2

Having failed to find support for the hypothesis of impaired feature encoding as responsible for the slowness of D.M.'s letter-by letter reading, we turn to another possibility: that he suffers from difficulties in integrating the visual features that constitute written material. Work by Treisman and others has previously shown that this process of feature integration is a prerequisite for normal perception, and when overtaxed may lead to illusory conjunctions in arrays made up of multiple features [6, 45, 62, 64]. Also, a second factor that may conceivably be responsible for the very slow letter by letter reading in D.M. is simply a deficit in the processing of multiple items in sequence, that is in shifting attention from one item to another.

To examine the possibilities of either a deficit of feature integration or of serial processing in D.M., a second visual search experiment was conducted, requiring subjects to integrate combinations of visual features for correct performance —conjunction search. The literature on the topic [3, 46, 59, 60, 63, 65, 69] indicates that normal subjects generally search for a conjunction target by a serial examination of the stimuli presented through focused attention, which either terminates at target detection or when all stimuli have been examined (serial self-terminating search [53]). If D.M. either suffers from a deficit in integrating visual features or in performing a sequential examination of a series of items, the effect of the number of items displayed on RTs will be higher than that shown by a group of normal controls.

Method

Subjects. D.M. and four well trained normal control subjects, matched to D.M. for age, education level, and handedness took part in this experiment.

Materials and stimuli. The target was a black X. On each trial, a variable number of distractors was presented. Distractors were white Xs and black Os and were displayed, on each trial, in equal numbers. These stimuli were 5.5 mm wide × 6.2 mm high. The background on which stimuli were displayed appeared gray and was made of an alternation of white and black small dots. No mask accompanied the array. The search stimuli remained visible until a response. Other aspects of the materials and stimuli used in this experiment were as stated in the Method section of Experiment 1.

Procedure. The task required subjects to indicate verbally (yes/no reponse), as rapidly as possible while avoiding errors, whether a black X was present in a stimulus array made of 2, 4, 6, 8, 10 or 12 items. One target was present on half the trials and none in the other half.

The experiment involved two factors. Those were: target (two levels, present or absent), and the number of items presented (six levels, 2, 4, 6, 8, 10 or 12). The experiment was run in five separate blocks of 60 trials each. Five trials in each condition were distributed randomly in each block. Subjects were seated at approx. 40 cm from the display screen.

Some of the trials were eliminated due to failure of the subject's verbal response to trigger the microphone. This happened on 1.0% of trials for D.M. and on 0.7% of trials for the control subjects.

Results and discussion

Figure 3 shows the average RTs of D.M. and of the control subjects during the search for a conjunctive target. Linear regressions of RTs as a function of the number of items displayed are shown separately for each condition in Table 3. The error rates observed in Experiment 2 are presented in Table 4. The correlations between RTs and error rates were not significant (−0.09 for D.M.; 0.17 for controls), indicating the absence of a speed–accuracy trade-off.

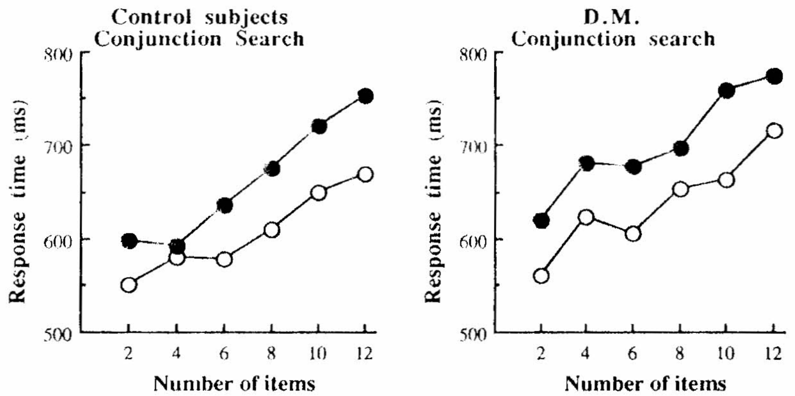

Fig. 3. Average RTs observed in the control group and D.M. in each condition of Experiment 2— conjunction search. Empty symbols = target-present trials. Filled symbols = target-absent trials.

Table 3. Linear regression analyses of RTs as a function of the number of items displayed in the conjunction search task (Experiment 2). Conventions are the same as in Table 1

Subjects	Target	Intercept	Slope	95% confidence interval	% of variance
Controls	Present	523	11.9	1.5/22.3	96
	Absent	542	17.1	8.7/25.5	96
D.M.	Present	543	13.4	—	90
	Absent	598	14.7	—	92

An ANOVA performed on the correct RTs observed in the control subjects revealed a main effect of the number of items [$F(5, 15) = 10.8$; $P < 0.001$] and a marginally significant effect of target presence [$F(1, 3) = 9.7$; $P = 0.05$]. The interaction of target × number of items failed to reach significance [$F(5, 15) = 1.9$; n.s.]. Accordingly, the linear regression analyses of RTs as a function of the number of items displayed indicated linear increases of RTs with number of items that were only slightly larger on target-absent than on target-present trials. The lack of a significant difference in the effect of the number of items as a function of target presence suggests that subjects performed the search through a serial exhaustive process [53]. This is rather unusual, as conjuction search is generally performed in a serial self-

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Table 4. Error rates (in %) observed in the conjunction search task (Experiment 2)

Subjects	Number of items	Target present	Target absent
Controls	2	0.0	0.6
	4	4.0	0.8
	6	0.0	0.8
	8	8.0	1.5
	10	6.0	2.1
	12	4.0	2.3
D.M.	2	8.0	0.0
	4	0.0	0.0
	6	4.0	0.0
	8	8.0	0.0
	10	0.0	0.0
	12	12.0	4.0

terminating manner, where slopes are twice as large on target-absent as on target-present trials. Nevertheless, a search pattern similar to that observed in Experiment 2 has been reported in several experiments where, as here, the number of items to be searched through was rather small [4, 26, 43]. It has been suggested before that a serial exhaustive process in conjunction search occurs when subjects can examine the entire stimulus array without eye movements [4, 26]. An ANOVA applied on errors rates only showed a main effect of the number of items [$F(5, 15) = 3.7$; $P < 0.05$]. This effect showed a tendency for error rates to increase with the number of items presented (Table 4).

The ANOVA performed on D.M.'s results also indicated main effects of target presence [$F(1, 279) = 25.8$; $P < 0.001$], and of number of items [$F(5, 279) = 12.5$; $P < 0.001$]. The interaction of target × number of items was not significant [$F(5, 279) < 1$]. In agreement with these results, regression analyses showed linear increases of RTs as a function of the number of stimuli which were similar for target-present and target-absent trials. Both the target-present and target-absent slopes observed in D.M. fell within the 95% confidence interval of the slopes seen in the normal controls. An analysis performed on error rates observed in D.M. suggested some variation in accuracy as a function of condition, but this did not reach significance [$\chi^2(11) = 16.8$; n.s.].

D.M.'s results in a task requiring the search for a conjunction target are remarkably similar to those observed in the normal controls. Thus, his RTs were much within the same range as those seen in the control group and the effect of the number of items was just the same in D.M. and in the normal controls. From this, we may conclude that D.M.'s very slow letter-by-letter reading is not caused by a disorder in integrating visual features, nor by a deficit in performing a serial examination of a sequence of items.

EXPERIMENT 3

Experiments 1 and 2 have provided observations which do not support the hypothesis of a low-level visual processing deficit as being responsible for pure alexia in D.M. One aspect which has not yet been examined in D.M. however, and which is a main factor according to Rapp and Caramazza's [47] account of letter-by-letter reading, is the processing of horizontal arrays of items. As indicated earlier, these authors argued that their patient suffers from a left-right gradient in the accuracy of feature representation. It is conceivable that a similar gradient may not have had any effect on D.M.'s performance in the two previous experiments due to particular aspects of the methodology used. Also, it is conceivable that D.M.'s performance was normal in Experiments 1 and 2 merely because the complexity of the stimulation used was too low for any deficit to be manifest. Experiment 3 was designed to address these possibilities.

Possibly the most striking demonstration of a feature processing gradient in RAPP and CARAMAZZA's [47] patient was obtained through the use of the partial report procedure [54]. In this task, their subject showed a very steep performance decrement with rightward target displacements within the stimulus array. Thus, accuracy was 100% for the leftmost item in a three-letter string and dropped to about 30% for the rightmost letter. The partial report paradigm thus appeared well suited to demonstrate a low-level visual deficit in processing horizontal stimulus arrays in D.M. if he suffers from any.

In one part of the experiment, subjects were asked for the full report of an array of six briefly exposed letters presented in two rows. In another, the task required the report of only one of the items displayed. The letter to be reported in this partial report task was indicated by a 50 msec bar probe which immediately followed stimulus exposure. If D.M. suffers from a deficit in representing letter features in the rightmost positions, he should show a markedly lower performance for items located on the right than for those located on the left of the array in both the full report and partial report tasks. No performance gradient of this sort is to be expected from the normal control subjects [36, 37].

Method

Subjects. D.M. and four well trained normal control subjects, matched to D.M. for age, education level, and handedness took part in this experiment.

Materials and stimuli. On each trial, an array made of two rows of three letters was presented for a duration of 150 msec. This particular stimulus arrangement was chosen due to D.M.'s dense right-hemianopia, which required left-hemifield exposures. The use of stimulus arrays made of a single row would have prevented the presentation of numerous items on each display and could have precluded any spatial location effect to appear in the data. Stimulus letters were randomly selected uppercase consonants which were between 3.4 and 5.2 mm wide × 6.2 mm high. Any letter could appear only once in a display. Each letter was separated from the one nearest to it by a distance of 1 cm. The right end of the stimulus array was located 1 cm to the left of a central fixation point of 2.0 mm in diameter, which was displayed for 1.5 sec before each trial. In the partial report condition, the probe indicating the letter to be reported was a vertical bar 4.1 mm high presented for a duration of 50 msec, 1 cm above (for upper row targets) or below (for lower row targets) the target letter. The onset of the bar probe was simultaneous with the offset of the stimulus array. All stimuli were black on a white background.

Procedure. In the full report condition, subjects were required to name all the letters presented. In the partial condition, only the target indicated by the bar probe was to be reported. Subjects were instructed to be as accurate as possible and no time pressure was applied. The experiment was run in two separate blocks: one made of 20 trials for the full report task, and one of 60 trials for the partial report task. One of D.M.'s trials in the full report task was accidentally lost during data analysis.

Results and discussion

Since the main interest of this experiment resided in the effect of stimulus location along a horizontal axis, results were collapsed according to the lateral location of the item within the row in which it was presented. These results are shown separately for the control subjects and D.M. in Fig. 4.

Results of the control subjects showed a uniformly high performance level, with no significant effect of stimulus location in either the full [$F(2, 6) = 1.5$; n.s.] or partial [$F(2, 6) < 1$] report tasks. In contrast, the analysis applied on D.M.'s results indicated a significant effect of stimulus location on accuracy in the full report task [$\chi^2(2) = 20.5$; $P < 0.001$].

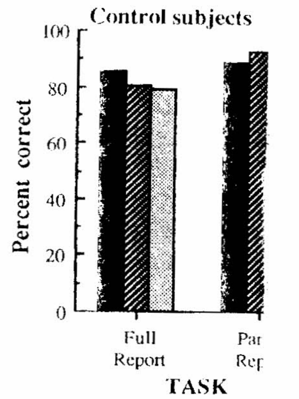

Fig. 4. Percentage of correct target r
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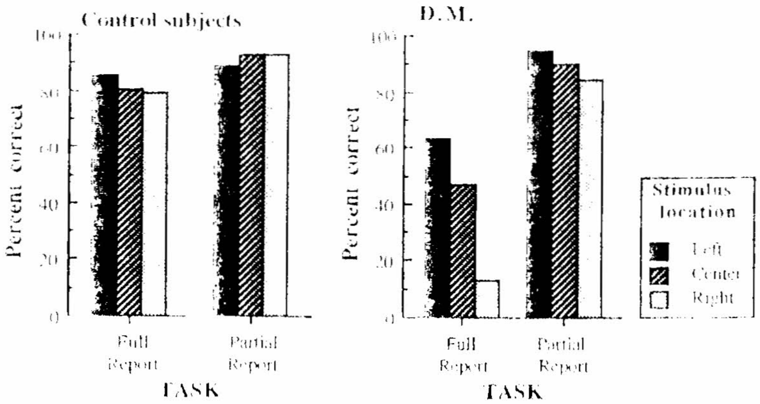

Fig. 4. Percentage of correct target report as a function of the horizontal location of the stimulus in the control group and D.M. in Experiment 3 — full and partial report.

However, no effect of lateral target location was observed in the partial report task [$\chi^2(2) = 1.11$; n.s.].

Direct comparisons of accuracy levels between the normal controls and D.M. were performed. In the full report task, D.M.'s accuracy was 3.4, 2.5 and 6.4 S.D. below the averages observed in the normal controls for the leftmost, center and rightmost stimulus locations, respectively. This positions D.M.'s performance below the lower limits of the 95% confidence intervals establised for the control group at all stimulus locations in the full report task. In contrast, for the partial report task, D.M.'s accuracy falls within the 95% confidence intervals established for the control group at each of the target locations. Thus, for a target located at the leftmost of the array, D.M.'s performance was 0.7 S.D. above the average of the normal controls. His performance was 0.4 and 1.2 S.D. below the averages of the control group for the center and rightmost target locations, respectively.

D.M.'s performance in the full report task was rather poor and accuracy was much lower for letters located to the right of the array than for letters located to the left. In marked contrast, D.M.'s partial report performance showed no significant accuracy gradient as a function of the horizontal location of the target. Moreover, for each of the target locations examined in this task, his percentage of correct responses was within the range of normal performance, as established from comparisons against the results of the control group. This discrepancy between full and partial report performance in D.M. is inconsistent with an impairment of feature encoding. Indeed, from the procedure used in Experiment 3, it should be expected that the quality of feature representation subjects could extract from the display is the same in the full and partial report tasks. Thus, in the two tasks, the conditions under which the stimuli were exposed were identical. Moreover, it cannot be said that the bar probe, which indicated the letter to report in the partial report task, served as a cue that helped D.M. to focus his attention on the target and thus obtain a better feature representation for this item. Indeed, this probe was only presented when no additional feature information could be extracted from the display, that is, immediately *after* the offset of the stimuli. From this, it may be concluded that the low-level perceptual processes involved in feature encoding and, possibly, other operations contributing to the elaboration of a structural description of the stimulation presented, did not constitute the limiting factor responsible for D.M.'s poor performance in full report. By extension, the present results suggest that the general slowness of the letter-by-letter reading performance in D.M. cannot be attributed to an impairment of these low-level perceptual operations.

If an impaired representation of visual features is not at the origin of the discrepancy between D.M.'s full and partial report performance, then what is the factor which may explain this difference? One possibility is that the discrepancy takes its origin in the different loads the full and partial report tasks put on the letter identification process. Clearly, letter identification was required in Experiment 3 since subjects had to explicitly report what the stimuli presented were. Just as clearly, an accurate description of the shapes of the letters displayed is not sufficient to determine *what* they represent—i.e. their identity. An additional processing step is required for this. It may be assumed that this step is the mapping of the structural description of the items displayed, that is a representation of their shapes, to knowledge representations of their identities. Ultimately, for a perfect performance, six such mappings had to be executed in the full report task. That is, subjects were required to report, and therefore identify, as many letters as they could from the six they were shown. However, in the partial report task, the identification of only one letter was sufficient for an accurate performance.

With a brief exposure duration such as that used in Experiment 3, observations reported by Pashler [42] suggest that, in normal observers, identification of the items presented is based on a rapidly fading iconic trace of these stimuli. At this point in the processing sequence, items have not yet been identitified but only exist as structural descriptions. If access to representations of letter identities is impaired, what this means is that a large performance discrepancy between full and partial report should follow, as we observed here in D.M.

Even if access to letter identities is slowed down to some degree, it may be possible to identify the letter indicated by the bar probe before the iconic trace of the target has faded away. This would then lead to normal or close to normal performance in the partial report task. In contrast, in a full report paradigm, a subject with impaired access to letter identities is at a great disadvantage compared to normal subjects. For the latter, the identification process may be sufficiently rapid that they are able to report several items before the icon has decayed. If the identification operation is slowed down however, fewer items may be reported within the duration of the iconic trace. This would then result in impaired full report performance relative to control subjects. The next experiment will test the hypothesis of impaired access to letter identity representations in D.M.

EXPERIMENT 4

The previous experiments have failed to provide any indication in D.M.'s results for an impairment of low-level perceptual processes. These observations thus suggest that D.M. does not suffer from a deficit in extracting information as to the shape of the visual stimulation to which he is exposed. As suggested above, another hypothesis that could account for his very slow letter-by-letter reading is that of a deficit in character *identification*—that is in contacting internal representations of the identities of letters from an intact structural description of the input.

In order to test this hypothesis, we designed a letter-search task in which it may be assumed that it was necessary for the subjects to sequentially identify the individual characters displayed in order to perform the task correctly. Several steps were thus taken in order to prevent subjects to use some template match strategy—i.e. base their responses on a structural description of the stimuli—to perform the task. Before each trial, a letter name was

presented auditorily. This letter
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Half the letters presented were
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Method

Subjects. D.M. and five well trained
handedness took part in this experimen

Materials and stimuli. The target subje
letter was presented auditorily immed
presentation was controlled by the comp
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and between 4.8 and 6.2. mm in height.

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They were displayed at random location
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Procedure. The task required subjects
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The experiment involved two factors.
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Some of the trials were eliminated due
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Results and discussion

Figure 5 shows the average R
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An ANOVA performed on th
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presented auditorily. This letter acted as the target on that particular trial and subjects were required to report whether it was present in an array made of a variable number of letters. Half the letters presented were in lowercase and half in uppercase. Also the target was in lowercase on half the trials and uppercase on the other half. Finally, the letters used in this experiment all have very different shapes when presented in their lowercase or uppercase forms. Besides these particular measures taken in order to ensure that identification of the stimuli presented be necessary for a correct performance, most other aspects of the task used in Experiment 4 were similar to those of the preceding experiments. Thus, as in Experiments 1 and 2, subjects had to search for a particular target in stimulus arrays made of a variable number of items and the task required a verbal yes/no response. Also, the stimuli used in Experiment 4 were letters, as was the case in Experiment 3.

Considering the nature of the task required in Experiment 4, it was assumed that subjects would have to perform a search involving the sequential identification of individual letters either until target detection or until the stimulus array has been processed exhaustively. From this, it was expected that RTs would increase linearly with the number of items presented and that these slopes may be attributed in large part to the operation of letter identification. Under the hypothesis of impaired letter identification, it was therefore predicted that the effect of the number of items on RTs, reflecting the time required to process individual letters, would be abnormally large in D.M.

Method

Subjects. D.M. and five [illegible] normal control subjects, matched to D.M. for age, education level, and handedness, took part in this experiment.

Materials and stimuli. The target subjects had to search for was a letter which varied from trial to trial. The target letter was presented auditorily immediately before the beginning of each trial [illegible]. The [illegible] presentation was controlled by the computer. The search stimuli used in this experiment were the letters A, B, F, G, N and R in both their lowercase and uppercase versions. The size of the letters was between [illegible] and [illegible] mm in width and between 4.8 and 6.[illegible] mm in height. All the stimuli were black on a white background.

On each trial, a variable number of distractors was presented. These were selected randomly within the non-targets letters for that trial. Half the distractors were lowercase and half uppercase. On half the trials, the target was lowercase and on the other half it was uppercase. The search stimuli remained visible until the subjects responded. They were displayed at random locations to the left of a central fixation point. Other aspects of the material and stimuli used in this experiment were as stated in the Method section of Experiment 1.

Procedure. The task required subjects to indicate verbally (yes/no response) as rapidly as possible while avoiding errors whether the target letter was present in a stimulus array made of 2, 4, 6 or 8 letters. One target was present on half the trials and none in the other half.

The experiment involved two factors. These were: target presence (two levels: present or absent); and the number of items presented (four levels: 2, 4, 6 or 8). The experiment was run in [illegible] blocks of [illegible] trials [illegible]. [illegible] trials in each condition were distributed randomly in each block. Subjects were seated [illegible] approx. [illegible] cm from the display screen.

Some of the trials were eliminated due to failure of the subject's verbal response to trigger the microphone. This happened on none of the trials for D.M. and on 1.5% of the trials for the control subjects.

Results and discussion

Figure 5 shows the average RTs observed in D.M. and in the control subjects during the search for a letter target on the basis of its identity. Linear regressions of RTs as a function of the number of items displayed are shown separately for each condition in Table 5. Error rates are presented in Table 6. The correlations between RTs and error rates were not significant (−0.12 for D.M.; 0.16 for controls), indicating the absence of a speed accuracy trade-off.

An ANOVA performed on the correct RTs observed in the control group revealed main effects of target presence [$F(1, 4) = 13.1$; $P < 0.05$], and of number of items [$F(3, 12) = 14.0$; $P < 0.001$], and an interaction of target × number of items [$F(3, 12) = 6.4$; $P < 0.01$]. Simple

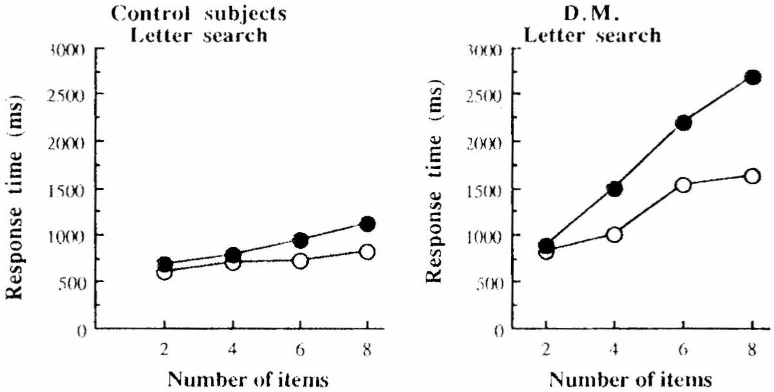

Fig. 5. Average RTs observed in the control group and D.M. in each condition of Experiment 4—letter search. Conventions are the same as in Fig. 3.

Table 5. Linear regression analyses of RTs as a function of the number of items displayed in the letter search task (Experiment 4). Conventions are the same as in Table 1

Subjects	Target	Intercept	Slope	95% confidence interval	% of variance
Controls	Present	554	32.9	18.5/47.3	95
	Absent	525	71.3	36.8/105.7	99
D.M.	Present	500	148.6	+	94
	Absent	282	306.5	+	100

Table 6. Error rates (in %) observed in the letter search task (Experiment 4)

Subjects	Number of items	Target present	Target absent
Controls	2	0.0	0.0
	4	0.8	0.0
	6	3.4	0.0
	8	5.0	1.7
D.M.	2	4.2	0.0
	4	8.3	0.0
	6	29.2	0.0
	8	16.7	0.0

effects of the target × number of items interaction indicated significant effects of the number of stimuli on both target-present [$F(3, 12) = 15.1$; $P < 0.001$] and target-absent [$F(3, 12) = 11.5$; $P < 0.005$] trials. Congruent with these large effects of the number of items, regressions showed substantial linear increases in RTs as a function of the number of stimuli displayed (Table 5). The effect of number of items on RTs was approximately twice as large on target-absent trials as on target-present trials, which indicates a serial self-terminating

search [53]. An analysis of varianc
controls did not show any significa
The ANOVA performed on D.
[$F(1, 170) = 88.7$; $P < 0.001$], and
interaction of target × number of ite
of the target × number of items inter
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[$F(3, 170) = 93.0$; $P < 0.001$] trials.
RTs as a function of the number of it
slopes were approximately twice a
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performed on the error rates reveal
condition [$\chi^2(7) = 28.0$; $P < 0.001$].
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individual letters reflects a deficit aff
we argue that the disorder occurs at
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required to determine if the stimul
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search [53]. An analysis of variance performed on the error rates observed on the normal controls did not show any significant effect.

The ANOVA performed on D.M.'s results indicated main effects of target presence [$F(1, 170) = 88.7$; $P < 0.001$], and of number of items [$F(3, 170) = 94.9$; $P < 0.001$], and an interaction of target × number of items [$F(3, 170) = 11.5$; $P < 0.001$]. Simple decomposition of the target × number of items interaction showed significant effects of the number of stimuli presented on both target-present [$F(3, 170) = 19.6$; $P < 0.001$] and target-absent [$F(3, 170) = 93.0$; $P < 0.001$] trials. Linear regressions indicated very large linear increases of RTs as a function of the number of items displayed. As was the case for the control data, these slopes were approximately twice as large on target-absent trials as they were on target-present trials (Table 5), indicating again a serial self-terminating search process. An analysis performed on the error rates revealed a significant variation in accuracy as a function of condition [$\chi^2(7) = 28.0$; $P < 0.001$]. As can be seen in Table 6, all of D.M.'s errors in the letter search task consisted in a failure to find the target. The frequency of these errors increased markedly with the number of items presented.

As indicated previously, the result of main interest in our visual search tasks is the rate at which RTs increased with each additional stimulus. In the present experiment, as argued above, a major part of the effect of additional letters on RTs may be attributed to the operation of identifying individual letters. It can be seen in Table 5 that the time required by D.M. to process an individual letter is dramatically longer than that observed in the normal controls. Thus, his slopes on both target-present and target-absent trials are far above the upper limits of the 95% confidence intervals established for the corresponding slopes in the control group.

A number of different operations may potentially contribute to the abnormally large effect of the number of items we observed on D.M.'s performance in Experiment 4. Those are: (1) the encoding of the features of an individual letter; (2) the integration of these features; (3) the identification of the letter; (4) and the time to shift the focus attention from one item to the next. Any of these operations may, in principle, be responsible for the slowed rate of letter processing in D.M. However, the observations reported in Experiments 1–3 indicated that the operations of feature encoding, feature integration, and attention shifts from one item to another are normal in this patient. On the basis of these considerations, it appears that the very large difference between the control subjects and D.M. in the time needed to process individual letters reflects a deficit affecting the operation of letter identification. Specifically, we argue that the disorder occurs at the point where an intact description of the shape of an item is matched to a representation of the identity of the letter, an operation which was required to determine if the stimulus was the target or not in Experiment 4. The next experiment will provide further evidence for a deficit affecting the processes involved in mapping a structural description of a letter to a representation of its identity in D.M.

EXPERIMENT 5

The results reported so far have demonstrated a deficit in the identification of single characters in D.M. No evidence for a disorder affecting the low-level perceptual processes responsible for the elaboration of a structural description of the visual input was found, despite our concerted attempts. One question still left open concerns the specific mechanism that might underlie D.M.'s identification deficit. A more detailed examination of the processes that must occur for correct identification is required.

A common assumption behind models of visual identification is that this operation requires a match between an appropriate description of the shape of a perceptual object and the internal representation of the identity of that object. A second assumption is that a given object would contact—or activate—not only its own internal representation but also neighboring representations that are structurally close to that of the target [25, 35]. Within this framework, we may assume that explicit identification occurs when the signal-to-noise ratio of activation between representations of the identities of known objects exceeds a certain threshold [2, 33].

Two selection mechanisms may be involved in achieving the signal-to-noise ratio required for explicit identification. First, the shape description of a given target must *activate* the representation that corresponds to its identity. Through this process however, other, competing representations may also be activated because of the structural overlap that exists between them and the target. In order to achieve a proper contrast between signal and noise, a second selection mechanism must come into play. This consists in the *inhibition* of representations of items that compete with that of the target for identification.

The observations reported in Experiments 1, 2 and 3 have suggested that D.M. is quite able to construct an adequate structural description of visual stimulation. Also, his ability to identify visually presented letters (Experiments 3 and 4), however slow it may be, suggests that internal representations to this type of written material are still available. From this, we may hypothesize that D.M.'s character identification deficit results from an impairment of the processes involved in matching a shape description of the input to the appropriate identity representation. Specifically, we suggest that the selection mechanisms—activation or inhibition—necessary to obtain a signal-to-noise ratio that exceeds the identification threshold are impaired for D.M.

Experiment 5 tested this hypothesis through the use of a structural similarity priming paradigm. In this task, subjects were asked to identify a single target letter. Preceding this target by a variable SOA, a letter prime was presented. This prime was either identical, similar, or very different in visual appearance from the target. Assuming that the prime mostly activates its own internal representation but also activates representations of structurally close items, the hypothesis of impaired selection processes in D.M. predicts that the time required to identify the target will be higher if it is preceded by a prime similar to it than by any other prime. That is, given a prime that is similar to the target, the activation of the prime's internal representation will largely decrease the signal-to-noise ratio that may be obtained from the target, relative to the other priming conditions. Indeed, those other piming conditions should mostly activate either the target representation (identical prime) or a representation which is not a structural neighbor of the target (structurally different) prime. If selection processes required for identification are impaired in D.M., a similar prime should therefore increase RTs relative to the other priming conditions.

In contrast to these expectations for D.M., previous experiments that used a similar paradigm suggest that the normal controls should show a response competition effect [16, 57], with response times higher with any prime letter that is associated to a response different from the target.

Method

Subjects. D.M. and four well trained normal control subjects, matched to D.M. for age, education level, and handedness took part in this experiment.

Materials and stimuli. Materials were identical to those described in Experiment 1.

The stimuli used were the uppercase letters H, M, O and Q. These letters were grouped into two pairs (H–M and O–Q). Each member of a pair was very similar to the other, and letters were very dissimilar betweens pairs. Selection

of these letters was based on the confusion m
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The target letter was presented 1 cm to the
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Procedure. The task required subjects to i
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Results and discussion

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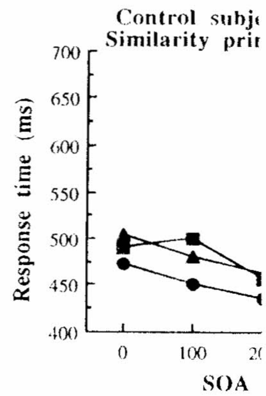

Fig. 6. Average RTs observed in
Experiment 5—similarity priming. Pri

Table 7. Error rates (in %) obser

Subjects	SOA
Controls	0
	100
	200
	300
D.M.	0
	100
	200
	300

of these letters was based on the confusion matrices reported in a number of publications [21, 32, 58, 66]. Similarity was operationally defined as the confusability between a given pair of letters in those confusion matrices. The width of the letters varied between 4.1 and 5.1 mm and all were 6.2 mm high.

The target letter was presented 1 cm to the left of a central fixation point. The prime was shown in duplicate, 1 cm above and below the target location. The fixation point remained visible for 1.5 sec before the onset of the prime letters. The stimulus onset asychrony (SOA) between the prime and the target was variable (0, 100, 200 or 300 msec). All stimuli (target and prime) remained visible until the subject responded.

Procedure. The task required subjects to name the target as rapidly as possible while avoiding errors.

The experiment involved two factors. Those were the similarity relation between prime and target (three levels, identical, similar, or different), and the SOA between target and prime (four levels: 0, 100, 200 or 300 msec). The main dependent measure was RT. The experiment was run in three separate blocks of 120 trials each. Ten trials in each condition were distributed randomly in each block. Subjects were seated at approx. 40 cm from the display screen.

Some of the trials were eliminated due to failure of the subject's verbal response to trigger the microphone. This happened on none of the trials for D.M. and on 1.0% of the trials for the control subjects.

Results and discussion

Average RTs observed for each priming condition in the control subjects and D.M. are presented in Fig. 6. Error rates, which were very low, are shown in Table 7. The correlations between RTs and error rates were not significant (r = 0.07 for D.M.; 0.00 for controls), indicating the absence of a speed accuracy trade off.

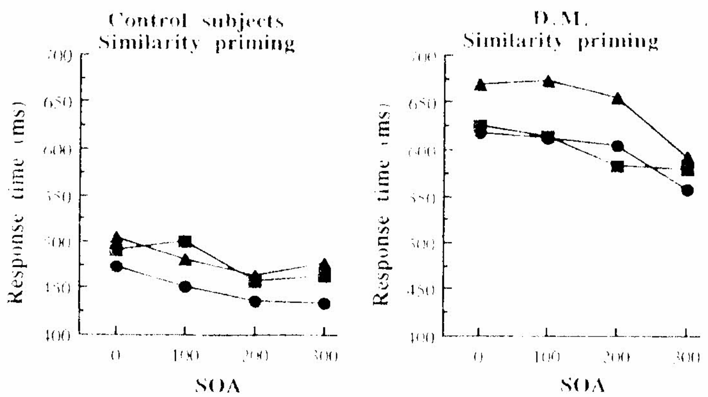

Fig. 6. Average RTs observed in the control group and D.M. in each condition of Experiment 5—similarity priming. Primes: circles—identical; triangles—similar; squares—different.

Table 7. Error rates (in %) observed in the Similarity priming experiment (Experiment 5)

Subjects	SOA	Identical prime	Similar prime	Different prime
Controls	0	0.0	0.8	0.0
	100	0.9	0.0	0.0
	200	0.0	0.8	0.8
	300	0.0	0.0	0.0
D.M.	0	0.0	0.0	0.0
	100	0.0	3.3	0.0
	200	3.3	0.0	0.0
	300	3.3	0.0	0.0

An analysis of variance performed on the average RTs for the control group revealed main effects of prime [F (2, 6) = 10.0; $P<0.05$] and of SOA [F (3, 9) = 10.3; $P<0.005$], along with a significant interaction between those two factors [F (6, 18) = 3.1; $P<0.05$]. The main effect of SOA indicated decreasing RTs with increasing time intervals between the prime and target. Pairwise comparisons with t-tests indicated that, at each SOA between prime and target, RTs were shorter with a prime identical to the target than with primes either similar to, or different from the target (for all comparisons, $P<0.01$). This pattern of priming effects was present in each of the control subjects. An ANOVA applied on the error rates observed in the normal controls did not reveal any significant effect.

An ANOVA performed on the RTs observed in D.M. also revealed main effects of prime [F (2, 345) = 8.3; $P<0.001$] and of SOA [F (3, 345) = 6.3; $P<0.001$]. However, the interaction of those two factors was not significant [F (6, 345) <1], although it is clear that the priming effect which is apparent at SOAs of 0, 100 and 200 msec (Fig. 6) was no longer present at an SOA of 300 msec. As was the case with the normal controls, D.M.'s RTs decreased with increasing SOA between prime and target. Pairwise comparisons indicated that RTs with a prime identical to the target were shorter than with one which is similar ($P<0.01$). In contrast to the results seen in the control group however, no difference between 'identical' and 'different' primes was seen (average RTs were 598 and 601 msec, respectively). The analysis applied on error rates showed no significant effect of condition on accuracy [χ^2 (11) = 9.1; n.s.]

A first aspect of the results which is worth noting is the large overall RT difference between D.M. and the control group (Fig. 6). Indeed, with all conditions pooled, D.M. took, on the average, 147 msec more than the normal controls to respond to the target. This is in marked contrast with the results of Experiments 1 and 2, in which D.M. and the control subjects showed RTs which were roughly within the same range. Considering that the task used in Experiment 5 required the identification of a target letter whereas this was not the case in Experiments 1 and 2, these large RTs observed in D.M. may be taken as evidence congruent with the hypothesis that his letter indentification is defective.

However, the most important result of Experiment 5 is the difference between D.M. and the control group in the pattern of RTs across priming conditions. As predicted on the basis of the literature on normal individuals, the control subjects showed what may be considered as a response competition effect. That is, any prime which is associated with a response that is different from the target led to an increase in RTs. In marked contrast, D.M. failed to show a response competition effect, since RTs in "identical" and "different" priming conditions did not differ. However, a prime similar to the target resulted in a marked increase of RTs relative to the other priming conditions.

The evidence presented in the previous experiments markedly constrains the range of acceptable accounts for D.M.'s letter processing deficit. Thus, it has been shown that D.M.'s letter processing impairment takes place after an appropriate encoding of the shape of the items has been achieved, but that he demonstrates a large increase in the time to process individual letters when identification is required. By elimination, one plausible account for D.M.'s character processing disorder is that he suffers from a deficit at the letter identification stage, that is in the processes involved in matching an adequate structural description of the input with the corresponding internal representation of the identity of the item.

As indicated previously, we have assumed that this matching process mainly involves activatory as well as inhibitory interactions between a representation of the shape of the target presented and internal representations of letter identities. The goal of these processes is

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Table 8. Relationship
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selectivity, that is the achievement of a strong enough signal-to-noise ratio of activity of one identity representation over its competitors (i.e. other letter identities). Here, we argue, is the locus of D.M.'s letter identification disorder. Thus, as predicted from the hypothesis of faulty selection processes in identification, D.M.'s results in Experiment 8 indicate that exposure to a prime structurally similar to the target results in a high level of background noise activity which competes with the activation of the target. This markedly lengthens the time required for target identification relative to other priming conditions.

In order to provide a formal assessment of our account of D.M.'s letter processing deficit, a simulation of the similarity priming task was conducted. This simulation was based on part of the functional architecture proposed by the interactive activation model (IAM) of McClelland and Rumelhart [35]. The set of feature representation units proposed by this model was used here to represent the notion of a structural description of the stimuli presented, and the set of letter units of the IAM served as representations of letter identities. The details of the operation of the network and of the tests performed are presented in the Appendix. The various parameters of the networks were first set so that it could reproduce the pattern of priming effects observed in the control group in Experiment 8. Then, restricted modifications were done on some of its parameters in order to examine which type of change enabled a complete replication of the empirical similarity priming results of Experiment 8. The effect of SOA between prime and target was not considered in those simulations.

As predicted from the hypothesis of impaired activatory and inhibitory interactions between the levels of structural description and letter identity representations in D.M., a modification of the activation and inhibition weights between these two levels led to simulation results which closely replicated the empirical findings of our similarity priming experiment. These results are presented in Table 8. The correlation between the empirical observations and the results from the simulation that are shown in Table 8 was 0.99. The effect of several other types of damage to the network was also assessed. Those were a reduction in the strength of activation of feature units, a reduction in the probability of feature detection, and a variation (increase or decrease) in the strength of the input coming from the prime. None of these modifications to the normal network succeeded in replicating the pattern of priming effects observed in D.M.

Table 8. Relationship between the empirical priming effects obtained in the similarity priming experiment (Experiment 8) and the simulation of this task where the damaged model had reduced activation and inhibition weights from structural descriptions to letter identity representations

Prime	Subjects	RT (msec)	Model	RT (number of cycles)
Identical	Controls	448	Normal	19.0
Similar		481		21.6
Different		477		21.6
Identical	D.M.	598	Damaged	27.2
Similar		647		31.0
Different		601		28.6

The results of the simulations thus indicate that the hypothesis of damage to the processes by which a description of the shape of a letter is mapped onto the appropriate representation of letter identity is a viable account of D.M.'s impairment. In constrast, various other manipulations which affected low-level processing in the network failed to approximate the abnormal priming effects observed in D.M. in Experiment 5. This suggests that accounts resting on such low-level perceptual deficits are unlikely explanations for his letter recognition disorder.

GENERAL DISCUSSION

The main findings from the experiments reported here indicate a disorder specifically affecting the selection processes—activation and/or inhibition—involved in the identification of alphanumeric stimulation in a pure alexic patient, D.M. All the available evidence failed to suggest that this disorder is accompanied by an impairment of the processes responsible for the elaboration of a structural description of visual stimulation. Moreover, the simulations of the similarity priming experiment have provided observations which suggest that the hypothesis for this latter type of disorder in D.M. is inadequate to explain his pattern of priming effects in Experiment 5. An impairment of low-level perceptual processes therefore does not appear to be a necessary concomitant of pure alexia.

We turn now to a discussion of the possible implications of the single-character identification disorder observed in D.M. for word reading performance. Given the nature of his letter identification deficit, it is obvious that a strategy based on the explicit decoding of letter identities would be abnormally slow. The more fundamental question however, concerns the nature of the relationship between a letter processing deficit of the kind we have described, and the disruption of visual word identification observed in D.M.

Currently, most models assume that normal reading is performed in a hierarchic fashion, with letter units activated in a spatially parallel manner and mapped onto higher level orthographic representations [1, 10, 34, 35, 39, 40, 41]. Within this framework, what might be the consequences of an impairment in the selection processes that must occur for letter identification?

As indicated, faulty selection of letter identities leads to a decreased signal-to-noise ratio between the target and competing units. This implies that the spurious activation of letter identity representations that are structural neighbors of each letter in the word presented is transmitted to higher levels in the processing hierarchy. The failure to quickly resolve the identity of letters may have a deleterious effect on word reading. Conceivably, this could entirely prevent the processing of words as perceptual wholes and hence force the subject to rely on the laborious decoding strategy that is characteristic of letter-by-letter reading. On this account, word reading performance—at least as it relates to explicit identification—could be predicted entirely on the basis of variables that affect letter identification, without any measurable effect of purely lexical factors.

An alternative explanation may be considered however. In effect, the distinction between letter and word units appears rather arbitrary when applied to the question of explicit identification. Single characters, after all, have specific pronunciations and can be reasonably thought of as being represented in the same system that maintains the form of the whole words. In the limit, there are words in English, and many other languages, made up of a single character (e.g. a and I). On this account, D.M.'s disturbance in extracting the perceptual identity of letters may be part of a more general deficit within a larger system that deals with the recovery of alphanumeric code. The fact that D.M. retains the ability to explicitly identify letters but not words (without resorting to a letter-by-letter strategy) may be accounted for in terms of the difference between the density of the structural neighborhoods of letter and word representations. Two factors may contribute to this difference. First, in almost every

language, the number of character…
acceptable words is very large. Se…
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Before closing, we would lik…
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language, the number of characters used for writing is fairly restricted whereas the number of acceptable words is very large. Second, the number of structurally close neighbors of any single character is rather small. If orthographic neighborhood [12, 49, 54] is used as an index of structural closeness for words, then the number of confusable exemplars (the neighborhood density) is much higher for words than for letters. Failure of the selection mechanisms that we consider necessary for perceptual identification may lead to a decreased signal-to-noise ratio in the activation of single letter representations, and therefore exaggerate the time required to produce a response. However, this ratio is even more decreased for word representations due to the density of their neighborhoods, thus preventing explicit identification without recourse to a compensatory mechanism that decomposes the word into its constituent letters.

If this latter hypothesis is correct, rapid access to word forms must still be occurring in pure alexia, though as we have argued, at a sub-optimal level that precludes explicit identification. This hypothesis leads to the following predictions. First, under the assumption of whole word access, it is expected that D.M. would show effects of orthographic context on letter perception (e.g. word superiority effect) similar to those reported in other pure alexic patients under exposure conditions that preclude explicit word report [3, 48]. Second, it may be possible for patients to perform accurate lexical decisions under exposure conditions that do not allow them to explicitly identify the item presented [e.g. 13, 52]. Thus, in a lexical decision task, the subject does not necessarily have to select the target representation from neighboring ones to achieve a reasonable level of performance. Indeed, on the basis of empirical observations and the emergent properties of connectionist networks in reading tasks, Monsell *et al.* [38] have indicated that a subthreshold signal from the target representation relative to the activity of neighboring items may provide a sufficient basis to distinguish a legitimate word-form from a nonlexical item (see also Ref. [2]). Finally, the hypothesis of subthreshold whole-word access predicts that word naming latencies should be markedly affected by purely lexical variables, such as the frequency of the item and the density of its orthographic neighborhood.

All of these predictions have been verified by recent observations in D.M. We present here a brief summary of these results, which will be the object of a detailed report in later publications. Among the most important findings, these recent experiments have shown that D.M. does show an effect of orthographic context on the identification of letters within a string. This patient is also able to perform accurate word/pseudoword decisions without an effect of word length on RTs and without explicit identification of the target [7]. Finally, other experiments have shown that D.M.'s word naming latencies are markedly affected by lexical variables. Thus, in naming four-letter words, this patient shows an important reduction of RTs with an increase in the target's frequency. Moreover, the neighborhood density of the target also has a major impact on latency in this task. In particular, word targets which have no orthographic neighbor of a higher frequency are named much faster than words with several such neighbors.

Before closing, we would like to present some speculations pertaining to the topic of whether pure alexia may be considered as a unitary syndrome. Obviously, at the present time, this issue remains undecided — conceivably, the account we provide for D.M.'s pure alexia may not generalize to other cases. Nevertheless, it is interesting to note that the hypothesis of an impairment of the selective processes involved in the identification of alphanumeric stimulation may provide the explanation of possibly the most important behavioral discrepancy between various alexic patients, which relates to the dissociation between explicit word identification and word categorization [13, 52]. Indeed, not all alexic patients show such a dissociation [27, 44, 47, 68]. We suggest that this difference between subsets of pure alexic patients need not be taken as a *necessary* indication of qualitatively different underlying deficits. Within the explanatory framework proposed above for pure alexia, the parameter of main interest are those which affect the selective processes—activation and inhibition —involved in identification. It is easy to conceive that the *extent* to which these selective processes are impaired varies from one pure alexic to another. For example, in some patients, damage may be sufficiently moderate to permit word activation to exceed the threshold necessary for lexical judgements, whereas others may suffer from an impairment which is too severe for this type of performance. Further work will be necessary to determine empirically whether the account presented here for D.M.'s reading impairment may apply for other pure alexic patients.

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APPENDIX

The network used to conduct the simulation of the similarity priming experiment was, in most respects, identical to the letter processing portion of McClelland and Rumelhart interactive activation model [35] and comprised a feature level and a letter identity representation level. The feature input as well as the letter identity representations were the same as proposed by these authors. The equations used to compute the net input received by units, the activation level of units, and the response strength of letter identity units were also the same as those used in the IAM (see equations (1)–(6) in Ref. [35]).

The targets and primes were presented to the model through separate but identical sets of feature units. Both sets of feature units projected to a unique set of letter identity units. The magnitude of the weights from prime feature units to letter identities was 15% that of the projections from target feature units to letter identities. In all the simulations conducted, the onset of the prime and of the target was simultaneous.

The probability of making a response based on a given letter identity unit was based on a signal-to-noise ratio inspired by Luce's choice model [33]—see equation (7) in Ref. [35]. The response criterion was achieved when the probability of a response based on one of the letter identity units exceeded a value of 0.7.

Following is a list of some of the parameters used in the model, which remained invariant throughout all the simulations conducted: minimum and resting activation level of units = 0; maximum activation level of units = 1; decay rate of activation = 0.07; rate of integration of the activation of letter identity units = 0.05; growth rate of response strength as a function of activation = 10.

In each of the priming conditions, the targets tested were the letters A, B, C, D, E, F, H, I, J, L, O, P, Q, R, T and U. In the identical prime condition, the same input was presented to the target and prime feature units. In the similar prime condition, the prime was a letter which differed from the target by only one feature. In the different prime condition, the prime was a letter which had no feature in common with the target.

The weight parameters used to simulate normal performance were established as follows. The activation weight from features to letter identities was set to 0.005. Each letter identity unit had a recursive facilitatory connection to itself whose weight was of 1. These two values were fixed and changes in inhibitory connections from features to letter identities and between letter identities were then performed in order to provide an approximation of the performance of the control group in Experiment 5. The data presented in Table 8 for the control group were obtained with an inhibition from features to letters of 0.031 and an inhibition between letter identities of 0.35. The damaged model data shown in Table 8 was obtained with the following weights from features to letters: activation = 0.0025; inhibition = 0.011.

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DOPAMINE DEPEN
PATIENTS WITH PARK

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Abstract—This study tested the hy
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subjects and patients with Parkins
which the motor demands were c
intrinsic information about the re
tasks which employed stimuli co
arbitrarily associated with the res
differentially impaired in using in

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