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Visual Word Activation in Pure Alexia

DANIEL N. BUB

Neurolinguistics, Montreal Neurological Institute, Montreal, Canada

AND

MARTIN ARGUIN

Département de psychologie and Groupe de Recherche en Neuropsychologie Expérimentale, Université de Montreal, Montreal, Canada

A patient with pure alexia (DM) is shown to perform rapid and accurate lexical decisions for common words without the ability to recover their complete identity. We provide evidence using a speeded decision task that DM is not forced to rely on a laborious analysis of individual letter forms when judging the lexical status of orthographic patterns varying in length, though he clearly must use this approach to fully identify a word for explicit report. By contrast, the ability to rapidly classify a word apparently does not extend to judgements of its superordinate category. DM makes semantic decisions for visual words by adopting the same inefficient procedure he uses for verbal report of their identity. The results provide further constraints on the functional deficit responsible for pure alexia. We argue that DM is able to monitor the overall activation of word units without achieving full identification and that such a process may be a characteristic of the normal reading mechanism.

INTRODUCTION

Pure alexia, or letter-by-letter reading, as the syndrome is now called, is characterized by extremely slow (but on the whole accurate) performance in a variety of reading tasks, with massive effects of word length on response time. As a general rule, the patient will need 3 or 4 sec to read (name or classify) even common three-letter words (though response

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times for very short words may be considerably longer in some cases; c.f. Coslett & Saffran, 1989). Moreover, for every increase in word length by one additional letter, performance may be correspondingly slowed by 2 or 3 sec.

A complete interpretation of this striking disorder—which can occur in the absence of impaired language and, more dramatically, impaired writing or spelling—has remained elusive. Two different types of accounts have been proposed: One suggestion focuses on possible damage to peripheral mechanisms that map visual information (letter features or identities) onto word forms. A variety of such explanations have been formulated, including among others the notion that the syndrome may represent a general constraint on the ability to process multiple visual forms, (Kinsbourne & Warrington, 1962) or single-letter identities (Arguin & Bub, 1993; Friedman & Alexander, 1984; Reuter-Lorenz & Brunn, 1990). A weakness suffered by all current versions of this type of hypothesis is that the evidence mustered to support it is based essentially on the co-occurrence of a perceptual disturbance (e.g., the observation of abnormal effects on a letter matching task) with the characteristic profile of letter-by-letter reading. This type of correlation leaves the claim that the peripheral disturbance is directly responsible for the syndrome unproven (see Bub & Bub, 1988, for comments on the logic required to draw inferences from associations of deficits).

An alternative viewpoint is that pure alexia is the outcome of a more central disturbance, unrelated to the variety of perceptual deficits that may or may not be found in association with the disorder. Warrington and Shallice (1980) offer the following interpretation of letter-by-letter reading: A specialized mechanism, termed the visual word-form system, exists in the left posterior cortex, which parses letter strings into familiar orthographic units (ranging in size from graphemes to syllables and whole words) and categorizes them perceptually. This automatic synthesis of letters into higher-order reading units normally allows for rapid and accurate identification of written words. Letter-by-letter readers have lost the use of the word-form system—they can no longer extract familiar perceptual units from a spelling pattern—and must therefore rely on a compensatory strategy requiring the laborious identification of each separate letter in the word. Note that on this account, any impairment affecting the *explicit* decoding of each letter (e.g., restrictions on the processing of multiple visual forms) would dictate the relative efficiency of the *compensatory* procedure (consider the extreme slowness of the letter-by-letter strategy) but may have little to do with the more central deficit in word activation that lies at the core of the syndrome.

A strong version of the hypothesis put forward by Warrington and Shallice—that damage to the visual word system is so extensive in letter-by-letter readers that words have the perceptual status of a random string of letters—has been disconfirmed in a number of experiments. For one, there have been demonstrations that the syndrome does not invariably abolish an effect of orthographic context on letter perception (Bub, Black, & Howell, 1989; Reuter-Lorenz & Brunn, 1990), a result that is incompatible with the notion that no higher-level units are extracted from written words. Thus, JV, the patient studied by Bub et al., was much better at identifying all of the letters in a briefly exposed four-letter target word than a random string of four letters. Furthermore, while accuracy for any letter in a nonword sequence was strongly determined by its position (JV's performance deteriorated systematically across the array from left to right), no such gradient was observed for the perception of letters in words.

Hidden Reading Abilities in Pure Alexia

This initial result provides some evidence against the claim that letter-by-letter readers are denied all visual access to orthographic word forms, though we cannot reach any definite conclusions about the overall integrity of the mechanism (e.g., only a subset of orthographic units may be activated, entries may be prone to abnormal inhibitory effects, etc). More recently, additional work has uncovered a startling new feature of at least some patients' reading performance that, if confirmed, must significantly affect our understanding of the nature of the cognitive damage responsible for the disorder. Shallice and Saffran (1986) have described a letter-by-letter reader who appeared capable of carrying out lexical decisions (word/nonword discrimination) and semantic classification of words (e.g., living/nonliving) at an exposure duration which, the authors contend, was too brief for the patient to explictly identify or name the target items. Coslett and Saffran (1989) arrived at the same conclusion about covert word processing in their evaluation of four additional patients.

The possibility that there may be hidden, though fragile, word recognition in some patients that is masked by a reliance on a more artificial strategy may conceivably reflect the existence of two different modes of processing in the syndrome: a very slow concatenation of the word through explicit analysis of its constituent letters, allowing for complete identification, and a second more natural procedure that takes place by rapid, parallel synthesis of letters into word forms. According to a recent publication by Coslett, Saffran, Greenbaum, and Schwartz (1993), these two modes are not only distinct but may be mutually incompatible: asking the patient J.W.C. to emphasize full report of a word interfered with his ability to carry out semantic classification, while encouraging him to forego explicit identification and to concentrate on a forced-choice task (e.g., does the word refer to something edible?) yielded much better category judgements but poor naming.

What is the nature of the deficit in pure alexia that would still allow tacit reading to occur? We may distinguish three different kinds of explanations. One account is that the covert abilities of letter-by-letter readers depend on processing mechanisms that are functionally and anatomically separate from those normally used for reading. Coslett and Saffran (1989) argue for such an interpretation, based on the notion that the right hemisphere may have a reading mechanism, albeit a more limited one than the more fully developed system in the language hemisphere. On this interpretation, the lesion in pure alexia prevents access from both visual cortices to lexical and semantic components in the left hemisphere, but the right visual cortex still has access to words in the right hemisphere system. This form of reading is, however, limited to the covert processing of words, presumably because explicit identification requires the mediation of functional components in the dominant hemisphere.

Support for this claim by Coslett and Saffran derives primarily from their observation that when patients recover to some degree their ability to report the identity of briefly displayed words, explicit recognition performance is influenced by imageability (accuracy is greater for high imagery words than low imagery words) and grammatical class (nouns are reported correctly more often than function words). As these variables have previously been considered relevant to the hypothesis of a reduced language mechanism in the right hemisphere (Coltheart, 1983), Coslett and Saffran proposed that both explicit and covert word recognition in pure alexics are mediated by the right hemisphere. These authors further suggested that the recovery of explicit reading occurred because patients "regained access to the phonological lexicon of the left hemisphere, presumably by means of information transfer across the undamaged body of the corpus callosum" (p. 352). There are problems with the argument that the right hemisphere lexicon is responsible for the covert reading exhibited by these patients, however. The observation that the accuracy of explicit identification is affected by imagery and grammatical class does not directly establish that the right hemisphere lexicon is also responsible for covert reading. This demonstration would require that these same variables also affect covert reading, which has yet to be established convincingly. Some initial evidence by Coslett et al. (1993) does suggest that tacit lexical decisions in a pure alexic were affected by imageability and word class, but the data are preliminary in that other extraneous variables like orthographic neighborhood size were not equated between word lists (closed-class words like *this, these,* and *when* tend to have rather small neighborhoods while many high frequency nouns may have bigger ones). Hence, without strong proof, the argument that lexical and semantic processes in the right hemisphere are the basis for tacit reading in pure alexia must be regarded as tentative.

An alternative interpretation is that the damage causing letter-by-letter reading is specifically a failure in the conscious recovery of higher-level information from visual words, with unimpaired activation of lexical units. Marcel (1983), in an extended discussion of this possibility applied to a range of neuropsychological data, proposes that the "occipital cortex may deal not so much with analysis of sensory qualities comprising form and identity but with their recovery for awareness" (p. 276). The loss of awareness as the only consequence of the lesion responsible for pure alexia, however, does not accommodate the very serious constraints on the tacit abilities of letter-by-letter readers. Patients, while capable of above-chance classification, make numerous errors on less familiar words and tend to accept nonwords that are highly similar to words when engaged in a lexical decision task. Shallice and Saffran (1986) have commented that the lack of precision they observed in their patient's ability to discriminate words from nonsense words that were very wordlike must be taken as inconsistent with the view that the deficit only concerns the mapping of word-forms onto subsequent levels of representation.

These latter authors favored a modification of the hypothesis originally proposed by Warrington and Shallice (1980), i.e., that letter-by-letter reading is the outcome of a visual word-form deficit. Thus, they inferred that brain damage has compromised activation in the word-form system without completely destroying access to word-level units. According to Shallice and Saffran (1986), "These limitations, including the failure to identify the stimulus explicitly, could conceivably be explained in terms of decreased levels of activation within the system that normally subserves explicit identification. . . . Weak input from an impaired word-form system could allow sufficient activation of the corresponding semantic representation to activate other representations by spreading activation, but not enough to inhibit the competing possibilities which explicit identification requires" (p. 452).

Raising Some Doubts about Tacit Reading

While the claims for tacit reading in pure alexia are potentially of great interest, we should note that the evidence on which they rest is somewhat equivocal. For one, many patients, indeed perhaps the majority, have not been found to show tacit reading capability of the kind reported by Shallice and Saffran (for example, see the cases described by Patterson & Kay, 1982), an outcome that raises questions about the genuineness of the phenomenon. Coslett et al. (1993) argue that negative reports are inconclusive because the failure to obtain implicit effects may be due to subtle differences in task demands—asking the patient to first try and label a briefly exposed word and then to produce a semantic or lexical classification after the attempt need not reveal any hidden capabilities if the primary response is based on a letter-by-letter strategy that interferes with the desired whole-word procedure.

Nevertheless, the positive findings in the literature can also be faulted on methodological grounds: Direct comparison of performance on tests of identification and classification under the same viewing conditions are often not carried out, so that we have no clear idea of the extent of the dissociation in most cases. Also lacking is any strong evidence that patients use qualitatively different approaches to covert and explicit reading tasks. The available demonstrations are based on the occurrence of a reasonably accurate classification of words as legitimate forms or as members of a particular category when the patient denies any knowledge of their identity. We cannot draw any conclusion about the nature of the processing leading up to the lexical or semantic decision from this result, nor can we necessarily infer that it must be distinguished from the procedure mediating full identification. The fact that no measures of processing speed have been taken, nor poststimulus activation effects prevented by means of a pattern mask, leaves open the possibility that patients continue to process the words when they are removed from view, using the contents of sensory memory to retrieve the constituent letters. Enough information may be derived in this way to perform adequately on a forced-choice procedure, even though the patient has not processed the word fully enough to recover its identity. Howard (1989) argues for this type of explanation when considering his own data and concludes that he has "no evidence to support Shallice and Saffran's suggestion that different routines are responsible for reading and categorization."

In this paper, we further explore the question of covert reading in pure alexia. We have indicated that uncertainty surrounds not only the processes governing tacit reading but also the actual validity of the phenomenon itself. Perhaps the most serious methodological flaw limiting a clear interpretation of previous work is the assumption that merely restricting exposure duration (without further constraints on the uptake of letter information) will effectively prevent the habitual mode of processing adopted by the letter-by-letter reader. Unfortunately, without some measure of the actual time course of responding, we have no proof that the patient does not continue to use an abnormally slow procedure to obtain the letter information needed by him to classify a word after termination of the display (c.f. Howard, 1989), particularly when poststimulus effects are not prevented by the introduction of a patterned mask. Our emphasis is on the *speed* with which the patient carries out various tasks as well as his failure to explicitly report the identity of visual words. We ask whether any clear difference exists between the modes of processing used by the patient to classify or name words, on the assumption that forced-choice classification—given the observed dissociation in previous case reports—might be accomplished by the patient without resorting to the strategy required for complete identification. If we can establish this fact unambiguously, we then define the kind of

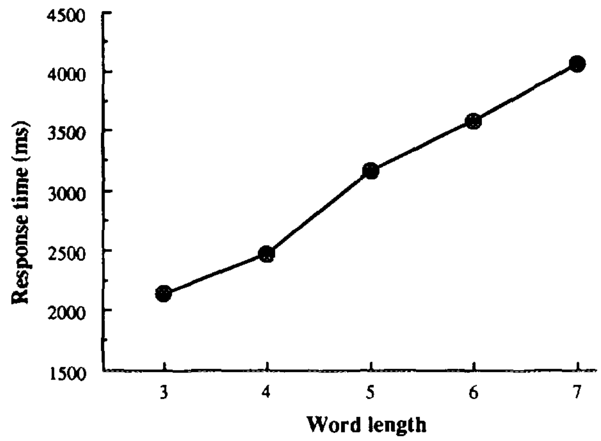

FIG. 1. Naming latency as a function of word length (Expt. 1).

information the patient can obtain from a word before he has access to its full identity. Are there important constraints on this information and if so, can we apply them to the development of a more precise interpretation of the reading deficit underlying pure alexia?

CASE DESCRIPTION

DM is a 24-year-old male who suffered a left parieto-occipital hemorrhage secondary to an occipital arterio-venous malformation. The hemorrhage was evacuated and the malformation excised 4 months prior to testing. CT scans obtained postsurgically revealed the lesion classically associated with pure alexia (i.e., left occipital damage), but with sparing of the corpus callosum (see Arguin & Bub, 1993, for further details).

EXPERIMENTAL ANALYSIS

Experiment 1: Naming Latency as a Function of Word Length

Preliminary assessment of the patient disclosed completely normal language ability, intact spelling and writing, and a very serious reading disorder marked by the slow and sequential identification of individual letters that is typical of letter-by-letter readers. Figure 1 displays the relationship between word length and correct reading time when the patient was asked to name, as rapidly as possible, 100 common words (frequency greater than 50 occurrences per million; Francis & Kucera, 1982) which were 3, 4, 5, 6, or 7 letters in length. Vocal response times were measured by a voice-activated relay from the onset of each word presented on a computer screen. The target remained in view until the response was initi-

TABLE 1
Reading Accuracy (% Correct) with Brief Exposures to Common Four-Letter Words (Expt. 2)

	Exposure duration (ms)				
	100	200	300	400	500
Full report	10.0	10.0	.0	30.0	40.0
First two letters	50.0	70.0	100.0	100.0	80.0

ated.[1] Errors were few (6% overall), but reading was extremely slow. The characteristic pattern of very long latencies (over 2 sec on average for three-letter words) coupled with a massive effect of length [slope: 498 ms/letter, $r^2 = .99$; $F(4, 88) = 4.7$; $p < .005$] are readily apparent.

Experiment 2: Reading Accuracy under Limited Viewing Conditions

Brief exposure of four-letter words disclosed a pattern of performance typical of patients with pure alexia (c.f. Warrington & Shallice, 1980). Sets of 10 words each (all with a frequency greater than 100 occurrences per million; Francis & Kucera, 1982) were displayed at various exposure durations (100, 200, 300, 400, or 500 msec). A different set of words was used in each display condition. Items were chosen so that their identity could not be guessed on the basis of the first two letters (e.g., FACT could also yield FACE or FAST if DM was unable to extract more than the initial bigram from the array). Each target item was immediately followed (ISI = 0 ms) by a patterned mask (Four Xs superimposed on four Os) for 50 msec. DM was simply asked to read the word or, of he could not, to report as many of the letters from the item as he was able to identify. Very few words could be read successfully, even with an exposure duration of 500 ms (Table 1). However, the effect of exposure duration on full report accuracy was marginally significant [$\chi^2(3) = 7.3$; $p < .10$]. In contrast, the patient was generally able to report the first two letters of any item (80% of trials overall; Table 1). This performance was significantly affected by target duration [$\chi^2(3) = 11.3$; $p < .05$].

LEXICAL DECISIONS

Experiment 3: Accurate Lexical Decisions without Overt Identification

We first became aware of the possibility that DM was capable of much more rapid categorization of visual word forms than is apparent from his

[1] Since DM has a dense right hemianopia, in this and in all other experiments, stimuli were presented slightly to the left of fixation.

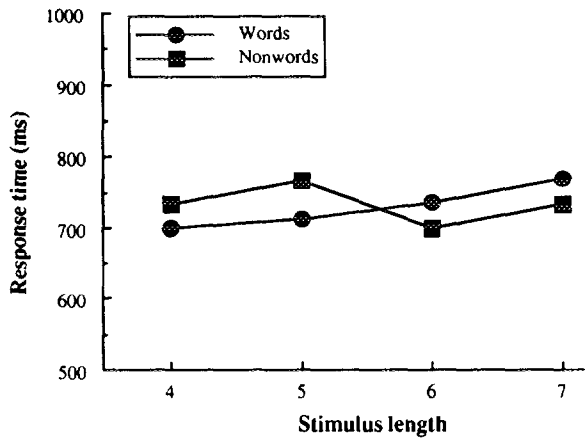

FIG. 2. Lexical decision latency as a function of stimulus length (Expt. 3).

overt naming latencies upon overhearing a chance remark he made during a test of his ability to discriminate legitimate English words (e.g., garden) from plausible nonsense words (e.g., gardel). To our surprise, the patient asked whether he was required to actually read the word, or merely to indicate if the target was real or nonsensical, a task he felt would not demand his usual letter-by-letter strategy. The results of an initial speeded lexical decision task were quite consistent with this possibility.

A total of 106 stimuli, half of them familiar words (greater than 100 occurrences per million in frequency; Francis & Kucera, 1982) and the remainder orthographically regular pseudowords (e.g., slint), were individually presented on a computer screen, and DM was asked to judge the lexical status of each one as quickly and as accurately as possible. Stimuli remained visible until the subject's oral response which was registered by a voice-key. Words and nonwords were 4, 5, 6, or 7 letters in length. Nonwords were generated by changing one or two letters in a word matched to the positive set for length and frequency. In general, the alteration was carried out on the last three-letter positions (e.g., family–famity), so that good lexical discrimination was required for accurate performance. Immediately after each response, timed correct to the nearest ms, the target disappeared and DM was asked to identify the word or nonsense word.

DM's correct lexical decision times are illustrated in Fig. 2. The patient's rate of correct lexical classifications, as a function of stimulus length, is shown in Table 2a. Accuracy of overt identification for targets that were correctly classified on the lexical decision response are reported in Table 2b. Analysis of the lexical decision times with factors of stimulus type (word/nonword) and length (4, 5, 6, or 7 letters) showed no main

TABLE 2
Accuracy (% Correct) of Lexical Decision (a) and of Overt Identification of the Target Given a Correct Word/Nonword Classification (b) (Expt. 3)

	Stimulus length (number of letters)			
	4	5	6	7
(a) Lexical decision				
Words	89.5	93.7	90.9	100.0
Nonwords	89.5	85.7	100.0	100.0
(b) Overt identification				
Words	82.4	40.0	10.0	14.3
Nonwords	58.8	8.3	16.7	12.5

effect [type: $F(1, 90) < 1$; length: $F(3, 90) = 1.0$; *n.s.*] or interaction [$F(3, 90) = 2.0$; *n.s.*]. Furthermore, lexical decision accuracy was not affected by stimulus length, either for words [$\chi^2(3) = 0.9$; *n.s.*] or for nonwords [$\chi^2(3) = 2.8$; *n.s.*]. In both cases, response accuracy was far above chance [for words and nonwords: $\chi^2(3) = 38.2$; $p < .001$]. Accuracy of overt stimulus identification given a correct lexical classification was much poorer however, as can be seen in Table 2b. The effect of stimulus length on overt identification accuracy was highly significant for both words [$\chi^2(3) = 17.4$; $p < .001$] and nonwords [$\chi^2(3) = 11.9$; $p < .01$], with decreasing accuracy for longer items. Despite a trend toward a larger error rate with words than with nonwords, the lexicality effect on overt identification failed to reach significance [$\chi^2(1) = 2.8$; *n.s.*].

The lexical decision performance observed here in DM is in marked contrast to that he exhibited in the overt identification task of Experiment 1. Thus, in word/nonword classifications, the patient showed no effect of stimulus length on either the response time or the accuracy measures. The dissocation is emphasized by the fact that DM's accuracy of stimulus identification after his correct lexical decisions was very poor and markedly affected by stimulus length.

Experiment 4: Lexical Decision vs. Naming Latencies

Clearly, DM's performance on tasks that demand complete identification of words—naming of items presented for unlimited durations or free report of masked items viewed briefly—diverges from his ability to carry out lexical decisions. To highlight the difference, we have compared DM's naming latencies for 60 high frequency words (greater than 100 occurrences per million; Francis & Kucera, 1982), three or four letters in length, with his lexical decision speed for the same items. The negative

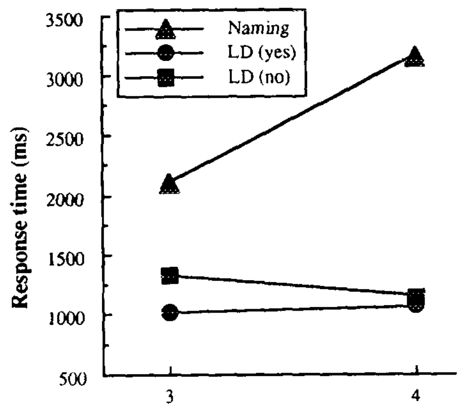

FIG. 3. Naming and lexical decision latencies as a function of stimulus length (Expt. 4).

items used in the lexical decision task were nonsense words ($n = 60$) generated from three- and four-letter words by changing one letter to produce highly plausible forms (e.g., lar, poon). The naming and lexical decision tasks were conducted separately. Stimuli were presented in random order and items remained visible until the subject's response. Oral response times were obtained through a voice-key.

The results indicated the usual dramatic effect of length on naming latency. However, the effect was considerably weaker for word/nonword decisions, which were also carried out much more rapidly (Fig. 3). Analysis of variance with response time in the naming and lexical decision tasks as the dependent measure revealed main effects of task [$F(2, 172) = 53.5, p < .001$] and of stimulus length [$F(1, 172) = 5.0, p < .05$], as well as a reliable task × length interaction [$F(2, 172) = 7.7, p < .001$]. Simple effects analyses confirmed the contrast in DM's performance according to task, with a significant effect of word length in naming [$F(1, 172) = 24.5, p < .001$], but none in lexical decision [$F(1, 172) < 1$, for both words and nonwords]. We should also emphasize the relatively high level of accuracy DM achieved on the classification task (Table 3), which was markedly better than chance (i.e., 50% accuracy) for both words [$\chi^2(1) = 21.6; p < .001$] and nonwords [$\chi^2(1) = 48.7; p < .001$] and was not affected by stimulus length [words: $\chi^2(1) = .0$; *n.s.*; nonwords: $\chi^2(1) = .9$; *n.s.*]. This indicates that the shorter response times shown by the patient in the lexical decision task are not simply due to a willingness to hazard a quick guess in the absence of good discrimination between words and nonsense words.

We should note that the remarkable discrepancy observed between naming latency and lexical decisions is not typical of letter-by-letter read-

TABLE 3
Lexical Decision Accuracy (% Correct) with Three- and Four-Letter Words and Nonwords (Expt. 4)

	Stimulus length (number of letters)	
	3	4
Words	79	81
Nonwords	91	97

ers. It has been our experience that patients with pure alexia often show a bigger influence of length on word/nonword decisions than on word naming. This observation is consistent with a report by Howard (1989) indicating that patients are generally obliged to adopt a serial approach to visual lexical decisions because they could not be sure if they had misidentified some of the letters in a target without checking each constituent element explicitly.

Experiment 5: Processing Modes for Lexical Decisions and Full Report—The Effect of Case Alternation

DM relies on a laborious strategy to process the identity of written words for a verbal report. This approach to reading would seem to require an explicit analysis of individual letters (we remain neutral on the question of whether the processing of letter units is strictly sequential or takes place slowly but in parallel) that he does not have to use when discriminating between words and plausible nonwords. A further test of this claim may be accomplished by examining how DM reacts to a manipulation that affects the ease with which the identity of individual letters can be extracted. Consider the two lists of words presented in Table 4. In normal individuals, alternating case has a small but measur-

TABLE 4
Examples of Words Printed in Normal and Case Alternated Formats (Expt. 5)

Format	
Normal	Case alternated
WOMAN	WoMaN
METHOD	mEtHoD
THROUGH	ThRoUgH
REALIZE	rEaLiZe
EARTH	EaRtH

able influence on the speed of reading (Besner & McCann, 1987), presumably because the changing format complicates the processing of abstract letter identity. We expect that DM would be highly sensitive to case alternation when he is asked to report a visual word, because he must resort to the conventional (and very inefficient) approach that is characteristic of letter-by-letter reading. The interesting question is whether his lexical decisions will be equally disrupted by case alternation. A negative answer would imply that DM's classification of words or nonwords does not depend on the same mode of processing required for complete identification.

DM's naming and lexical decision latencies were measured for items presented in either a normal or a case alternated format (see Table 4). Each task and condition was tested in separate blocks and with different lists of items that were similarly constituted. Each condition used 40 familiar words (all of a frequency greater than 100 per million) that were four, five, six, or seven letters in length (10 items per length). For lexical decisions, each list comprised, in addition to words, 40 legal nonwords (lengths of four, five, six, or seven letters; 10 items per length) made by changing one letter from a real word. Stimuli were presented for an unlimited duration on a computer screen and response latencies were measured by means of a voice activated relay.

The correct response times observed in each condition are illustrated in Fig. 4 and the percentages of correct responses are presented in Table 5. Confirming the observations of the previous experiment, correct response times were much longer for word naming than for lexical decision (words and nonwords, $F(2, 191) = 147.1$; $p < .001$). Furthermore, the effect of stimulus length was significant for the naming task [$F(3, 191) = 6.1$; $p < .001$] but not for lexical decisions (for words and nonwords, $F(3, 191) < 1$). In naming, case alternation led to a dramatic overall increase in response times ($F(1, 191) = 23.4$; $p < .001$] as well as to a significant increase in the effect of word length [$F(3, 191) = 2.7$; $p < .05$]. In contrast, stimulus format had no effect on lexical decision latencies, either for words or nonwords [all F's < 1].

Analyses of accuracy data indicated a larger error rate for lexical decisions on words than for naming [$\chi^2(1) = 4.8$; $p < .05$]. However, no significant effect of length [words: $\chi^2(3) = 3.1$; *n.s.*; nonwords: $\chi^2(3) = .7$; *n.s.*] or stimulus format [words: $\chi^2(1) = 3.1$; *n.s.*; nonwords: $\chi^2(1) = .7$; *n.s.*] was observed in the lexical decision task. Furthermore, lexical decision accuracy was markedly better than chance for both words [$\chi^2(1) = 33.8$; $p < .001$] and nonwords [$\chi^2(1) = 57.8$; $p < .001$].

The results of Experiment 5 provide strong evidence that the mode of processing adopted by DM for lexical decisions is not equivalent to the approach he needs to arrive at the complete identity of a word. Thus, whereas the case alternation manipulation led to a large increase of re-

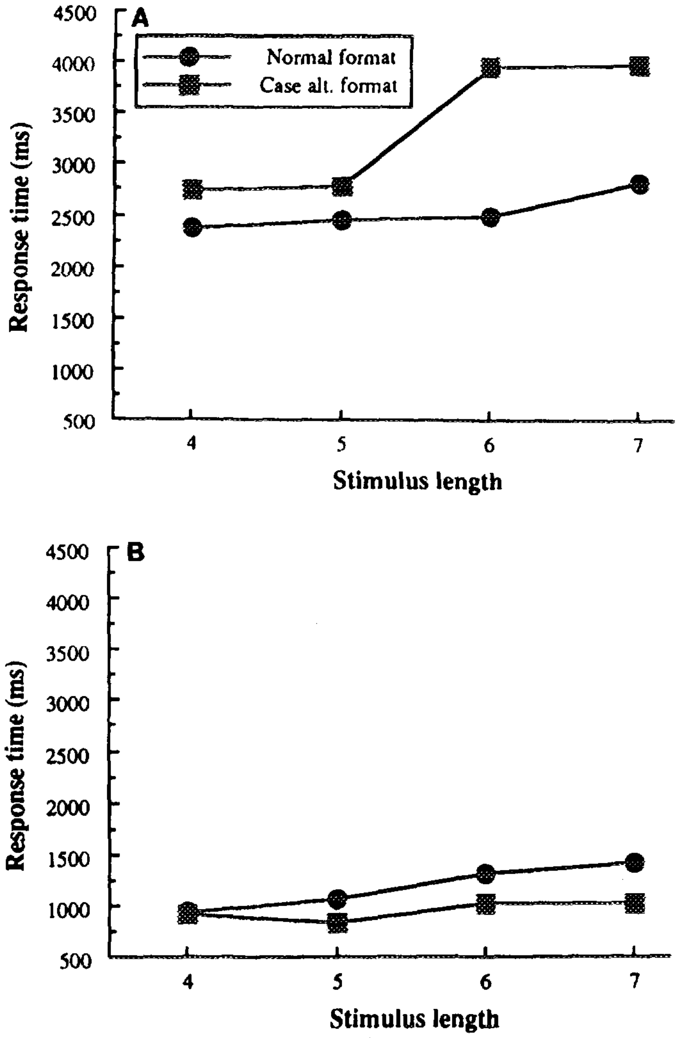

FIG. 4. Naming and lexical decision latencies as a function of stimulus length and format (Expt. 5). (A) Overt recognition, words; (B) lexical decision, words; and (C) lexical decision, nonwords.

sponse times and to an increase in the effect of word length in the naming task, no effect of stimulus format occurred in the lexical decision task. The present experiment also confirmed the previous observations from DM indicating he is capable of discriminating words from nonwords accurately without the massive effect of word length that characterizes his naming performance.

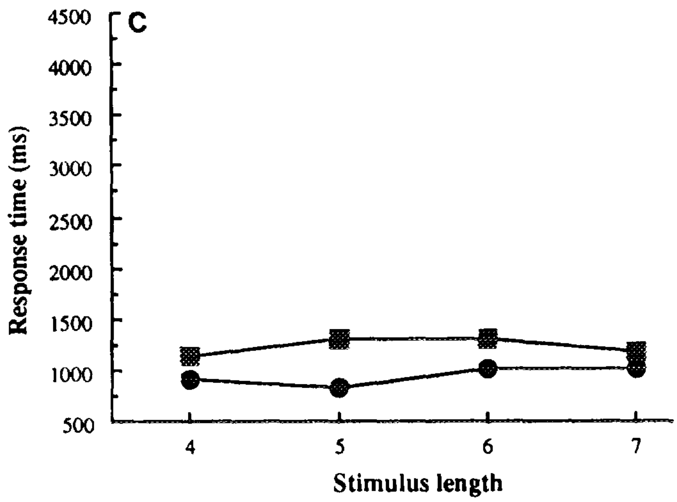

FIG. 4—*Continued*

Experiment 6: Constraints on Tacit Processing—Semantic Classification

A number of authors have claimed that tacit performance in letter-by-letter readers extends to semantic classification as well as lexical decisions (Shallice & Saffran, 1986; Coslett & Saffran, 1989). This possibility was tested in DM using a task requiring him to classify words varying systematically in length as referring to body parts (e.g., finger) or some

TABLE 5
Reading Accuracy (% Correct) in Word Naming and Lexical Decision with Items Printed in a Normal or Case Alternated Format (Expt. 5)

		Format	
	Length	Normal	Case alternated
Naming	4	90	90
	5	90	90
	6	100	90
	7	100	100
Lex. Dec. (words)	4	100	80
	5	90	80
	6	80	60
	7	70	100
Lex. Dec. (nonwords)	4	90	90
	5	90	100
	6	100	90
	7	90	90

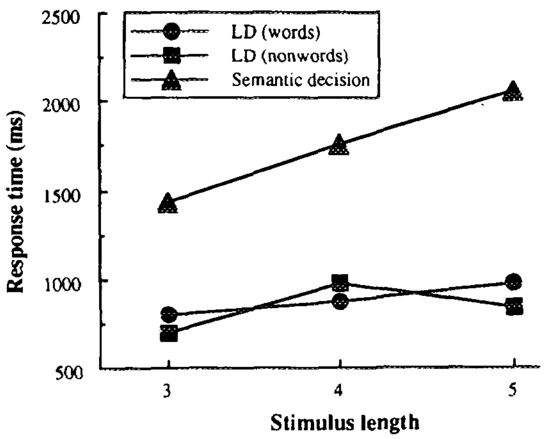

FIG. 5. Lexical decision and semantic classification latencies as a function of stimulus length (Expt. 6).

other kind of object (e.g., window). We chose the body part category because of the relatively high frequency of suitable words, which thus allows us to minimize the possibility that DM would have trouble on the task simply because the target items were not as familiar as those used for previous lexical decisions. Words ($n = 88$) were 3, 4, or 5 letters in length and were presented for unrestricted viewing. Items that did not refer to body parts ($n = 44$) were selected to indicate concrete objects. Word frequency was never less than 100 occurrences per million for any positive item.

By way of contrast to the semantic classification task, a number of the words used ($n = 46$) were presented again, randomly mixed with nonwords, for lexical decision. An equal number of nonwords were constructed by changing one or two letters in words taken from a set comparable in length and frequency to the positive items.

Correct response times are illustrated in Fig. 5 and accuracy is presented in Table 6. An analysis of variance applied on correct response times revealed much longer latencies for semantic classifications (1745

TABLE 6
Accuracy (% Correct) of Lexical Decision and Semantic Classification (Expt. 6)

	Stimulus length (number of letters)		
	3	4	5
Lexical decision/words	90.0	87.5	66.6
Lexical decision/nonwords	90.0	91.7	100.0
Semantic classification	80.0	93.9	94.7

msec) than for lexical decisions (words, 885.6 msec, nonwords, 838.6 msec) [$F(2, 149) = 52.2$; $p < .001$]. In addition, whereas a major increase of response latencies was observed as a function of word length in the semantic classification task [$F(2, 149) = 10.5$; $p < .001$], no effect of length occurred in lexical decisions [words: $F(2, 149) < 1$; nonwords: $F(2, 149) = 1.1$; *n.s.*]. Analysis of accuracy showed no effect of stimulus length in any task [semantic classification: $\chi^2(2) = 3.8$; *n.s.*; lexical decision/words: $\chi^2(2) = 2.9$; *n.s.*; lexical decision/nonwords: $\chi^2(2) = 1.0$; *n.s.*]. Despite very short response latencies, the rate of correct responses for lexical decisions was markedly better than chance [words: $\chi^2(1) = 19.6$; $p < .001$; nonwords: $\chi^2(1) = 32.8$; $p < .001$].

The main result of Experiment 6 is that DM is incapable of determining the semantic category of a word without responses that are much slower than we have observed for lexical decisions, and moreover which are strongly influenced by length. The tacit reading process available to DM, therefore, can mediate judgements on the status of a word as a legitimate orthographic unit, but apparently does not extend to information regarding its semantic category. This result is surprising and if confirmed must place important constraints on a theoretical interpretation of the mechanism responsible for covert word identification in letter-by-letter reading. The evidence we have obtained, however, seems to conflict with other reports indicating that some letter-by-letter readers are capable of well-above-chance levels of accuracy on semantic categorization tasks for words displayed briefly enough to prevent explicit identification. We may question the validity of these previous claims, though, on the following grounds. The ability to correctly assign a word to a category when the patient has not obtained sufficient letter information to uncover its identity does not tell us anything about the time course and nature of the underlying process responsible for the performance. If some letters have been extracted from the target—even by a slow procedure that is no different from the one mediating explicit report—the patient may have obtained enough information to categorize the word in a binary decision task without being able to report the identity.

Experiment 7: Further Details on Semantic Classification

We have obtained some data that supports the interpretation outlined above for the apparent discrepancy between DM and other letter-by-letter readers. DM was presented with 40 individual words (length varied between 4 and 7 letters) that referred to animals or objects for 500 msec followed immediately by a pattern mask. The patient was asked to guess whether the category items belonged to (animal/object). DM attains a relatively high level of accuracy in this task (Table 7) and his performance is much better than chance [$\chi^2(1) = 8.1$; $p < .01$].

TABLE 7
Accuracy (% Correct) of Semantic Classification with Stimulus Exposures of 500 ms (Expt. 7)

Animals	67%
Objects	79%

Animal/object classification was again used, but this time with an unlimited exposure duration and response time as the dependent measure. A total of 120 words, with an equal number of items having lengths of 4, 5, and 6 letters were presented. Half the stimuli were animals and half were objects. DM's average correct response time was very long (2191 msec) and an important effect of stimulus length (Fig. 6) was observed [$F(2, 83) = 5.7$; $p < .005$]. The effect of length on accuracy (Table 8) was not significant [$\chi^2(2) = 1.3$; *n.s.*].

Experiment 8: Passive Semantic Priming

Although we find that DM is limited to a slow procedure when deriving the meaning of words for explicit judgements of their category (at least for the categories we tested), we would hesitate to conclude that visual word forms have no direct access to semantic representations. If his ability to distinguish between words and pseudowords is based on the activation of lexical information, then other components of the reading mechanism, including those that derive meaning from words, may also be rapidly and automatically contacted, despite the fact that DM cannot use this information to perform the category judgements we required. On

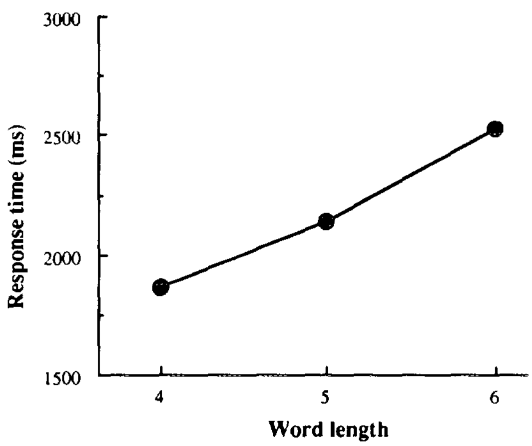

FIG. 6. Semantic classification latency as a function of stimulus length (Expt. 7).

TABLE 8
Accuracy (% Correct) of Speeded Semantic Classification with Unlimited Exposure Duration (Expt. 7)

	Stimulus length (number of letters)		
	4	5	6
Semantic classification	93.7	85.2	86.8

this hypothesis, the nature of the semantic representations that DM can activate would presumably be only a subset of their complete description. Since we cannot specify what primitives—if any—are available to him for explicit judgements, we cannot know whether his difficulty is the result of a mismatch between the superordinate judgements we have asked of him and the actual knowledge he has accessed, or a complete failure to map visual word units directly onto meaning.

We have looked for additional evidence that words make rapid contact with semantic information by examining whether lexical decisions are speeded for DM by the prior occurrence of a related word, displayed very briefly under passive viewing conditions and centrally masked. A number of studies have confirmed that priming may still occur in normal readers when words are presented below perceptual thresholds for conscious awareness (e.g., Marcel, 1983; Fowler, Wolford, Slade, & Tassinary, 1981). We have made use of a similar procedure to determine if, for DM, words continue to gain *fast* entry to semantic information, even though he apparently must rely on a much less efficient process to carry out explicit category judgements.

The details of the experiment are as follows: DM was asked to perform a lexical decision task with each target preceded by a briefly displayed priming event. He was told to look directly at the prime when it occurred but to make no response until the subsequent target was shown for classification. The target words (n = 140) and an equal number of orthographically legal pseudowords were presented for unrestricted durations and were terminated by DM's response (yes or no timed in ms from the onset of the target). Words were selected in pairs closely matched for length and frequency. For one member of each pair, a four-letter priming word was obtained that was semantically or associatively related to it (for example, LOCK with KEY). The matched control word (in this example, FAT) was combined with a neutral prime (the word ZERO). To obtain information on possible differences in semantic activation for common and less familiar words, half the priming words were high frequency items (greater than 100 occurrences per million), while the remainder were lower frequency words (less than 20 occurrences per million). Nonsense words were either preceded by real words (all four letters in length) comparable in frequency to the primes or by the word ZERO.

The experiment was repeated on two occasions (1 month apart) with different exposure durations for the prime. In one session, the prime words were presented for 200 msec followed immediately by a 50-msec mask (a row of X's superimposed on a row of O's). This was followed by a blank interval of 150 msec and then the target word or pseudoword. A further session provided a more stringent masking condition: The prime was exposed for only 50 msec before the occurrence of the patterned mask for an additional 50 msec. We should point out that DM was shown to be incapable of reporting more than 10% of familiar four-letter words at 200 ms exposure duration when he was asked their identity (see Table 1), even when permitted unlimited time to arrive at a response. A word passively viewed for 50 msec, with semantic activation being measured 250 msec after its onset, can be viewed as a stringent time window for monitoring the passive build-up of information given the extent of DM's failure on explicit report.

Correct positive response times to words preceded by semantic or neutral primes at the two exposure durations (50 and 200 msec) can be seen in Fig. 7. The means for each comparison (semantically related versus neutral primes) were obtained from target words matched for length and frequency, and therefore pairs of response times were only included if DM gave a positive response to both members in the lexical decision task.

There is a clear priming effect at both 50 and 200 msec exposure durations and no indication that the facilitation is reduced by a shorter interval between prime and target. A repeated-measures analysis of variance with prime duration (50 versus 200) and frequency (high versus low) treated as between-subject factors and prime type (associative versus neutral) as a within-subject factor indicated a significant main effect of priming [$F(1, 87) = 4.7$, $p < .05$], and no interaction between this variable and frequency or duration (all F's < 1[2]). As in the previous experiments that used the lexical decision paradigm in DM, accuracy (Table 9) was markedly better than chance [$\chi^2(1) = 268.8$; $p < .001$]. In addition, the rate of correct responses showed an overall benefit of priming by related words [$\chi^2(1) = 7.8$; $p < .01$].

[2] Though the interaction does not approach significance, the priming effect which is clearly apparent for low frequency words at 50 msec is insubstantial for high frequency words at this exposure duration. We have no explanation for this anomaly, although we do not believe that it has any particular theoretical significance. In any case, the question we are asking is merely concerned with establishing the overall possibility of automatic semantic access in DM at brief exposure durations and we leave open the more difficult issue of the variables that may potentially affect the occurrence of a positive result.

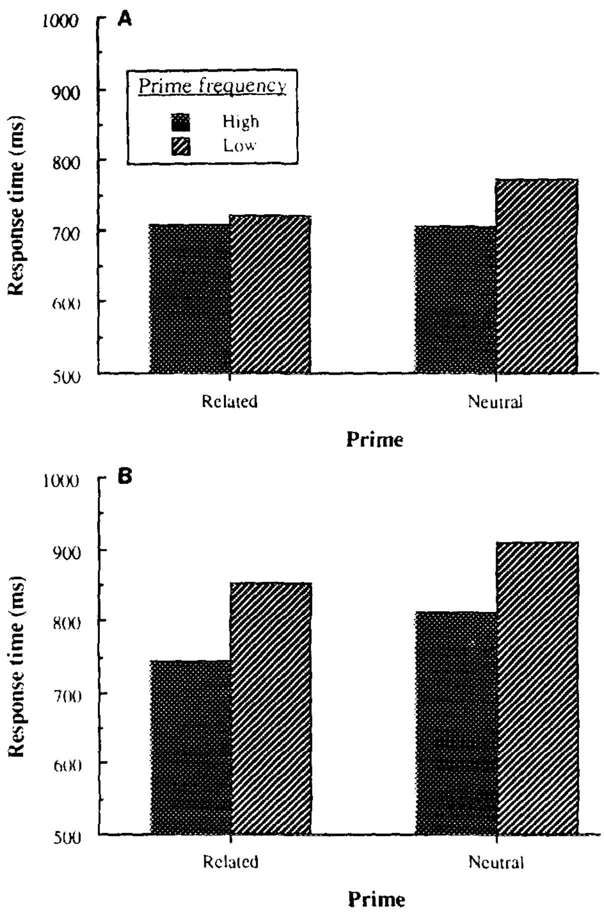

FIG. 7. Lexical decision to words as a function of priming condition (Expt. 8). (A) 50-msec prime, (B) 200-msec prime.

We conclude that DM must continue to have rapid entry to semantic information even for centrally masked words presented at 50 msec exposure duration and furthermore that such access extends to relatively uncommon as well as more familiar words.

GENERAL DISCUSSION

Pure alexia is characterized by very long oral reading times for words presented in free vision that increase systematically by several tenths of a second with each additional letter. When words are presented for a limited duration (e.g., 500 msec), the patient makes numerous errors in reporting them, and performance is again strongly dependent on word

TABLE 9
Accuracy (% Correct) of Primed Lexical Decision (Expt. 8)

	Prime duration (ms)			
	50		200	
	HI	LO	HI	LO
(a) Word targets				
Related prime	88.6	77.1	91.6	85.7
Neutral prime	82.9	60.0	88.6	57.1
(b) Nonword targets				
Word prime	86.5		94.3	
Neutral prime	76.1		88.6	

Note. HI, High frequency prime; LO, low frequency prime.

length. The extreme slowing of responses, apparent even for the shortest words, indicates that—whatever the nature of the process by which the letter-by-letter reader arrives at the final output—he must be relying on a procedure that is hampered by difficulty in establishing the perceptual identity of letters units. We find other evidence for a constraint on the skill with which letters are decoded by DM in the massive effect of case alternation on his speed of reading aloud, indicating that he has trouble deriving abstract letter identities from a display. We have also demonstrated in a further set of studies (Arguin & Bub, 1993) that this disturbance in identification extends to the processing of *single* letters, and that other prior stages of perceptual analysis (feature extraction and integration) are manifestly intact.

The evidence for an impairment in the explicit identification of letters has prompted a number of attempts to explain letter-by-letter reading simply as the outcome of a prelexical disturbance in the perceptual categorization of the visual units comprising a word. We have noted that this interpretation remains unconvincing from a purely methodological standpoint, given the absence of a clear proof that the letter-level impairment is causally related to the disrupted reading of whole words. However, the complexity of the syndrome and the need for a more elaborate account also become immediately apparent when we consider the empirical reports of tacit reading in some patients, occurring much more rapidly than would be expected from the laborious approach that is needed for explicit report.

DM, whose performance is taken as a representative instance of this phenomenon, is able to determine that a spelling pattern is a legitimate word as opposed to a pseudoword much more rapidly (average latency less than 1 sec) than we would expect from his speed of reading aloud (mean latency greater than 2 sec). He can do this type of classification with a relatively high degree of accuracy (overall error rates less than 20%) even when he cannot report the identity of the word. Typically, his verbal response under these circumstances is limited to the first few letters of the target (e.g., CARPET, "CA . . . that's all I could get") or an incorrect attempt to guess the word based on the initial portion (e.g., CARPET, "Was it cattle?").

We have obtained evidence that DM's ability to carry out lexical decisions is based on a relatively precise description of word forms—accuracy on negative trials remains well above chance even for items that differ only by a single letter from a legitimate word. This outcome should not be taken to imply that there are no major limitations on DM's preserved sensitivity to wordness, however. Our preference for moderate-to-high frequency words in the experiments we have described is worth commenting on here—as would appear to be the case for all other letter-by-letter readers who retain tacit classification of visual words, evidence that we have obtained and that will be reported elsewhere (Arguin & Bub, 1994) indicates that DM's performance on lexical decisions strongly depends on the familiarity of the target, going from well above chance for high frequency words to a majority of incorrect rejections (false negatives) on lower frequency items. The marked deterioration in the reliability of lexical decisions can also be seen in other descriptions of covert reading by pure alexics. Coslett and Saffran (1989), for example, used very familiar words (mean frequency of 446 per million) to obtain the high accuracy rate they observed for lexical decisions to briefly exposed items in the four patients they document. Shallice and Saffran (1986) report a change in d' from 1.84 to 1.10 as word frequency was altered from high (A or AA) to low categories (between 10 and 19 per million).

What conclusion can be reached from the fact that DM—and other letter-by-letter readers as well—is capable of discriminating common words from plausible alternatives under conditions that preclude explicit reporting of their identity? Taken in isolation, the mere dissociation between full report and a forced-choice decision regarding some aspect of a word's structure or meaning does not establish the possibility that the letter-by-letter reader has recourse to a process qualitatively different from the one mediating his overt labeling response. The widely raised criticism that evidence for reliable discrimination accompanied by a failure to report the identity of the target may be more a reflection of a bias against producing a verbal response under conditions of uncertainty (Dixon, 1971, in an extensive commentary aptly refers to this conservative bias as "when in doubt say nowt") is no less applicable to the issue of covert reading in pure alexia as it is to the more general question of perception without awareness in normal subjects (see Kunimoto, Miller, & Pashler, 1991, for a recent treatment of this issue).

But we have other reasons for arguing that DM cannot be relying on the same mode of processing to judge the lexical status of a visual word that he uses to arrive at its full identity. Two facts support this claim: First, tacit reading does not extend to semantic classification in real time, even though accuracy may remain above chance on this task when exposure duration is limited. We infer that DM is only capable of extracting information about the *orthographic* form of a word without resorting to the procedure he habitually adopts for complete identification, and that the covert judgements we have documented do not include the recovery of meaning. The evidence leads us to reject previous claims for direct semantic classification in other letter-by-letter readers, on the grounds that, without further proof, above-chance categorization of briefly exposed words may simply be due to partially decoded letter information that allows a forced-choice response but not the more demanding one of verbal report.

Analysis of the *time* taken by DM to carry out semantic decisions—a direct measure of processing efficiency—clearly demonstrates that performance is much slower and more affected by length than lexical decisions to words of comparable frequency. The speed with which a word is classified thus depends on the *level* of representation that must be contacted for the binary decision, a result that is difficult to explain in terms of the assumption that DM utilizes the same procedure for all reading tasks (full identification or tacit judgements). If classification of a word is much more rapid than reporting its identity only because DM may rely on partial letter information to guide his choice of response, then we can think of no reason why lexical and semantic decisions are not carried out with equal facility.

The null effect of case alternation on lexical decision speed compared to the massive effect of this manipulation on oral reading times provides further support against the claim that DM is using an equivalent mode of processing in the two tasks. If word decisions are accomplished more rapidly than verbal report simply because DM needs less detailed orthographic information, classification performance should still be heavily influenced by a manipulation that renders the identity of the letters in the word harder for him to establish. We might anticipate a somewhat reduced effect of case alternation on lexical decisions relative to explicit identification, given this hypothesis, but the fact that the speed and accuracy of word judgements are so resistant to a change in letter format that adds over 800 msec overall to DM's overt reading latencies, indicates (a) that he needs to carry out an explicit analysis of letter units for some tasks (e.g., verbal report) using a mechanism that is very inefficient and (b) he does not rely on the same mechanism to determine that a spelling pattern is a familiar word. DM's comments to us during his performance of the lexical decision task with case alternated lettering are worth a brief mention in this regard. His speeded judgements, even when correct, were often followed by a disclaimer once the target was removed from view, based on a subsequent false evaluation of a letter. For example, MoThEr "Yes!" (display is terminated) "No, wait, that can't be right. I think I saw m-o-t-k or something. Sorry about that, I'm wrong again."

We conclude that DM has immediate access to some information about the word that is pertinent to its lexical status, but that this representation cannot be used to determine the semantic category of the word or identify it for a verbal report without an additional explicit analysis of some or all of the letters. This compensatory process may be hampered by raising the difficulty level of perceptual decoding, even yielding a misperception under certain conditions, with no comparable effect on the direct translation of letter units into visual word forms.

The nature of DM's performance leads us to question an interpretation of covert reading based on the concept of a right hemisphere language mechanism. This dissociation between lexical and semantic classification is not an outcome that is accommodated easily within this hypothesis, unless we are willing to grant that neither the right nor the left hemisphere can achieve the kind of access to meaning from visual words that permits reasonably accurate forced-choice categorization. While this possibility cannot be entirely discounted, the explanation that we are currently pursuing is that the activation of word units in the lexicon has been reduced in strength in pure alexia to the point below the threshold for complete identification (Shallice & Saffran, 1986). If enough signal from the visual word-form system is generated, the patient may be able to make a familiarity judgement, though we would expect that accurate discrimination is only possible for more common words. Other covert effects may be found, however, if we look for the indirect products of lexical activation on aspects of performance that do not involve a decision on the lexical status of a spelling pattern. For example, the build-up of information from a low frequency word in the damaged system may not be sufficient to allow a discriminative response but semantic priming between related words may nevertheless be possible. Consistent with this point, we have obtained clear evidence that such priming does occur within a very short interval (less than 500 msec), despite DM's inability to judge the semantic category of a word without a laborious decoding strategy, even for words that are relatively uncommon.

Several current models of visual lexical access can accommodate the pattern of results we have observed in DM. If activation levels (or growth rates) in the word form system can be monitored, high frequency words may produce a sufficiently strong change to bias the decision towards a positive response before unique identification has been achieved. For example, McClelland and Rumelhart (1985) described a miniature system that not only computes the identity of *specific* word patterns and retrieves their pronunciation, but also has the additional property of greater activation over all the nodes in the system when a familiar pattern is encountered. The ability to estimate this value would allow correct decisions for common words in the absence of their particular identity. Such a monitoring process has also been described by Monsell, Doyle, and Haggard (1989) in a recent examination of the locus of word frequency effects in reading tasks. DM, we claim, is similarly making use of a property of the normal access mechanism to judge the familiarity of words, though for him, word-form activation rarely—if ever—proceeds to the point of complete identification.

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